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User's Guide Overview for Controlling Accidental Releases of Air Toxics

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16. ABSTRACT The User's Guide, the first in a series of manuals, presents an overview of available methods for identifying, evaluating, and controlling hazards in facilities that use, manufacture, or store acutely toxic chemicals that could be released into the environment. Hazardous chemicals and their key characteristics are discussed, followed by a discussion of the potential hazards in process and physical plant design and in operational procedures. Formal methods of hazard identification and evaluation are discussed, their major features are compared, and an overview of control principles for prevention, protection, and mitigation is presented. Examples of control technologies are listed, and an example guide for inspecting facilities is presented. Important references on the topic of accidental toxic chemical release prevention are cited.

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Accident Prevention	Stationary Sources	13L
Toxicity	Accidental Release	06T
Emission	Air Toxics	14G
Chemical Compounds		07B, 07C
Hazards		

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PREVENTION REFERENCE MANUAL: USER'S GUIDE
OVERVIEW FOR CONTROLLING ACCIDENTAL RELEASES OF AIR TOXICS

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ABSTRACT

Accidental air releases of toxic chemical must be prevented by all reasonable means, and when they do occur, appropriate measures must be taken to reduce their consequences. This User's Guide, which presents an overview of the methods available for identifying, evaluating, and controlling hazards in facilities that use, manufacture, or store acutely toxic chemicals that could be released into the air, is one of a series of manuals dealing with various aspects of toxic chemical releases. Other volumes focus on specific chemicals, on the procedures and technologies for preventing and protecting against accidental releases of toxic chemicals, and on ways to mitigate a release if it occurs.

First, a brief history of accidental releases and their control is presented. Hazardous chemicals and their key properties of interest are defined. Hazards in process operations that relate to process design, physical plant design, and to management and maintenance procedures and practices are examined. Formal methods of hazard identification are described and evaluated, and major features of the most common formal methods are compared. The principles of prevention, protection, and mitigation control are discussed, and example control technologies are listed. Finally, an example guide to facility inspections is presented.

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SECTION 1
INTRODUCTION

1.1 GENERAL BACKGROUND

Increasing concern about the potentially disastrous consequences of accidental releases of toxic chemicals has resulted from the Bhopal, India methyl isocyanate release on December 3, 1984, which killed approximately 2,000 people and injured thousands more. Concern about the safety of process facilities that handle hazardous materials increased further after the accident at the Chernobyl nuclear power plant in the Soviet Union in April of 1986.

While headlines of these incidents have created the current awareness of toxic release problems, there have been other, perhaps less dramatic, incidents in the past. These previous accidents contributed to the development of the field of loss prevention as a recognized specialty area within the general realm of engineering science. Interest in reducing the probability and consequences of accidental toxic chemical releases that might harm workers within a process facility and people in the surrounding community prompted the preparation of this manual and a planned series of companion manuals. The other manuals in the series will cover:

- Chemical specific information,
- Prevention control technologies, and
- Mitigation control technologies.

These manuals compile the technical information that is necessary for developing approaches to preventing and controlling accidental releases. They cover various aspects of release control, including identification of causes; methods of hazard identification and evaluation; and prevention, protection, and mitigation measures. Prevention involves design and operating measures applied to a process to ensure that primary containment is not breached. Protection focuses on the capture or destruction of a toxic chemical involved in an incipient release after primary containment has been breached, but before an uncontrolled release of the toxic chemical to the environment has occurred. Mitigation measures reduce the consequences of a release once it has occurred. The manuals are based on current and historical technical literature and they address fundamental considerations of the design, construction, and operation of chemical process facilities where accidental releases of toxic chemicals could occur.

Four types of releases are encountered in facilities that use, manufacture or store toxic chemicals:

- Releases from limited process upsets,
- Process vents,
- Fugitive emissions, and
- Accidental, sudden, large releases.

Accidental releases are the primary subject of this manual and of other manuals in the series.

The User's Guide is a general introduction to the subject of toxic chemical releases and to the broad concepts addressed in more detail in the other manuals. The manual gives a brief history of toxic chemical releases and overview of the accidental release problem. Primary industrial chemicals of concern are identified and the fundamental causes of toxic releases are summarized. Methods commonly used in hazard identification and evaluation are briefly discussed and an overview of the general principles of hazard control are presented. An example of the kind of guide to facility hazard inspections that can be developed from the information in this and other manuals is also presented.

The chemical-specific manuals in the series will focus on release hazard issues associated with specific chemicals in their most common industrial uses. The control technologies manual will focus on the fundamentals of process design, equipment design, and procedures and on how changes in these areas can help prevent and reduce the probability and magnitude of accidental releases. The mitigation manual will discuss ways of reducing the consequences of accidental releases.

The ultimate objective of controlling accidental chemical releases is to reduce adverse consequences to human health and to the general environment. The place of various controls in achieving this objective is illustrated conceptually in Figure 1-1. Each category of controls contributes to the reduction of the consequences of an accidental release. A full accidental release control program will contain some control methods from each of the categories listed in the figure.

1.2 HISTORICAL BACKGROUND AND ACCIDENTAL EVENTS OVERVIEW

The Bhopal incident, one of the most dramatic chemical accidents in history, eclipsed the 1976 major toxic discharge in Seveso, Italy, and numerous other significant, but less disastrous chemical releases over the years.

The historical development of concern about accidental releases tracks the general advance of loss prevention in the process industries. Much of that development has focused on fire and explosion protection. Since physical property losses are largest in these incidents, the magnitude of losses from fire and explosions has dominated industrial insurance issues for years. Accidental toxic releases have not been ignored, however. Lees (1) presents a summary table of major fire, explosion, and toxic release incidents in the chemical industry from the early years of this century through 1979. A listing of toxic releases taken from that table is presented in Table 1-1.

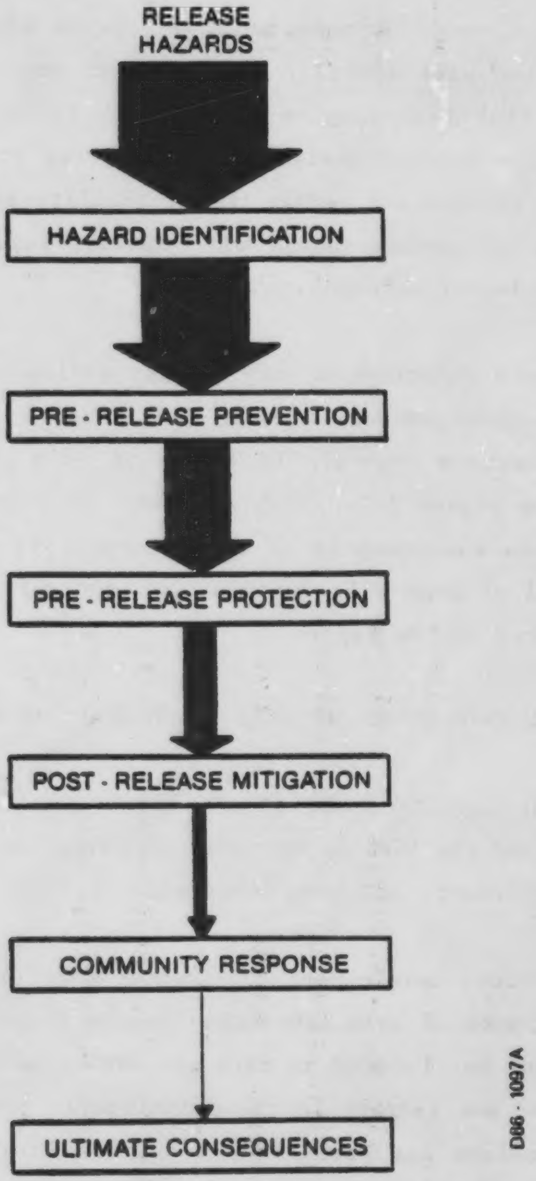

RELEASE HAZARDS
HAZARD IDENTIFICATION
PRE - RELEASE PREVENTION
PRE - RELEASE PROTECTION
POST - RELEASE MITIGATION
COMMUNITY RESPONSE
ULTIMATE CONSEQUENCES
D86 - 1097A

Figure 1-1. The role of various accidental release control measures in reducing the consequences of an accidental release.

TABLE 1-1. MAJOR TOXIC RELEASE INCIDENTS BETWEEN 1950 AND 1980

Date	Location	Chemical	Deaths	Injuries
1950	Poza Rica, Mexico	Hydrogen sulfide	22	320
1952	Wilsum, Germany	Chlorine	7	Unknown
1961	Billingham, Great Britain	Chlorine	0	Unknown
1961	La Barre, Lousiana	Chlorine	1	114
1961	Morganza, Lousiana	Chlorine	0	17
1962	Cornwall, Ontario	Chlorine	0	89
1963	Brandtsville, Pennsylvania	Chlorine	0	Unknown
1963	Philadelphia, Pennsylvania	Chlorine	0	430+
1966	La Spezia, Italy	Chlorine	0	Unknown
1967	Bankstown, Australia	Chlorine	0	5
1967	Newton, Alabama	Chlorine	0	Unknown
1968	East Germany	Vinyl chloride	24	Unknown
1968	Lievin, France	Ammonia	5	Unknown
1969	Crete, Nebraska	Ammonia	ca. 8	20
1969	Glendora, Mississippi	Vinyl chloride	0	Unknown

Source: Reference 1

(continued)

TABLE 1-1 (Continued)

Date	Location	Chemical	Deaths	Injuries
1970	Blair, Nebraska	Ammonia	0	Unknown
1971	Floral, Arkansas	Ammonia	0	Unknown
1973	Loos, British Columbia	Chlorine	0	Unknown
1973	McPherson, Kansas	Ammonia	0	Unknown
1973	Potchefstroom, South Africa	Ammonia	18	Unknown
1974	Nebraska	Chlorine	Unknown	Unknown
1976	Baton Rouge, Louisiana	Chlorine	Unknown	Unknown
1976	Houston, Texas	Ammonia	6	Unknown
1976	Seveso, Italy	Dioxin (TCDD)	0	Unknown
1977	Columbia	Ammonia	30	Unknown
1978	Baltimore, Maryland	Sulfur trioxide	Unknown	Unknown
1978	Chicago, Illinois	Hydrogen sulfide	Unknown	Unknown
1978	Youngstown, Florida	Chlorine	8	Unknown

Source: Reference 1.

Various other surveys also address accidental releases. A recent publication by the U.S. Environmental Protection Agency (EPA), the Acute Hazardous Events Data Base, examines the causes of toxic chemical accidental release events (2). Along with other statistics, this report presents the locations of toxic release events within a process facility, as shown in Figure 1-2. The causes of losses in the chemical and allied industries as shown in an insurance survey are presented in Figure 1-3 (3). Table 1-2 summarizes similar information from two other sources (4).

Examination of this information shows that it is difficult to absolutely quantify the distribution of accidental release causes; every survey results in a somewhat different distribution of causes. A likely reason for these differences is that every survey uses a different and fairly limited data set. Another possible reason is the difficulty in consistently defining the actual causes of a release. As an example, if a valve were to fail because of corrosion and result in an accidental release, the cause might be classified as valve failure, maintenance failure or design failure, depending on the classification criteria of the specific survey. Even within this complexity, however, some trends can be observed. A comparison of the information shows that faulty pipes and fittings are common causes of accidental releases.

The occurrence of such incidents tends to obscure the long and dedicated activity of numerous individuals and organizations who have contributed to the field of loss prevention. Some organizations that have been very active in this area, especially in the last two decades, include the Institute of Chemical Engineers (Britain), the American Institute of Chemical Engineers, the American Petroleum Institute, other organizations and many major corporations, especially in the chemical industry. Two leaders in this field have been Dow, which developed the well-known Dow Index for ranking process facilities for fire and explosion potential, and Imperial Chemical Industries, for modifying this index to the Mond Index, which includes toxicity in the ranking. Activity in both the public and private sectors in this area is intense,

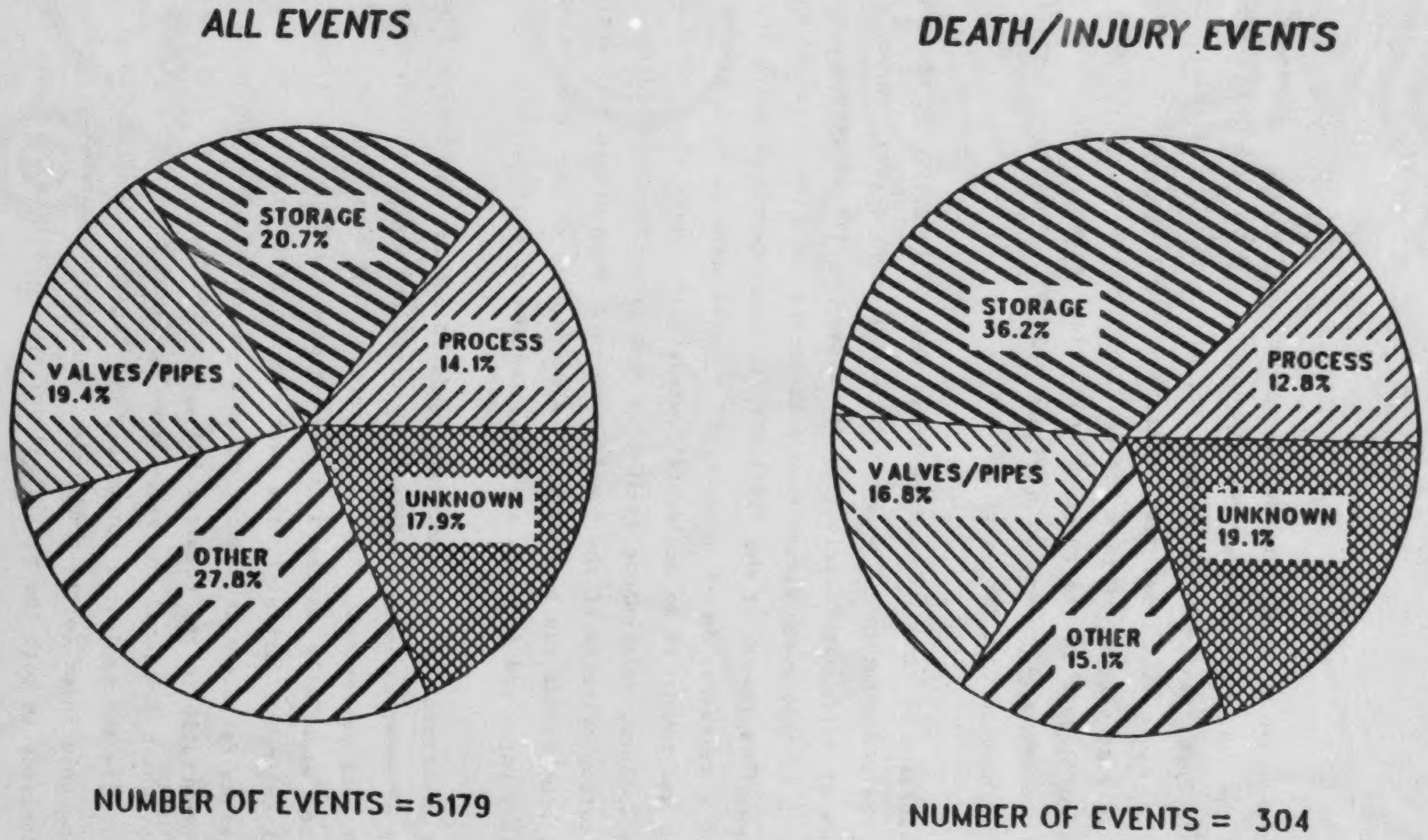


Figure 1-2. In-plant acute hazardous events by location.

Source: Reference 2.

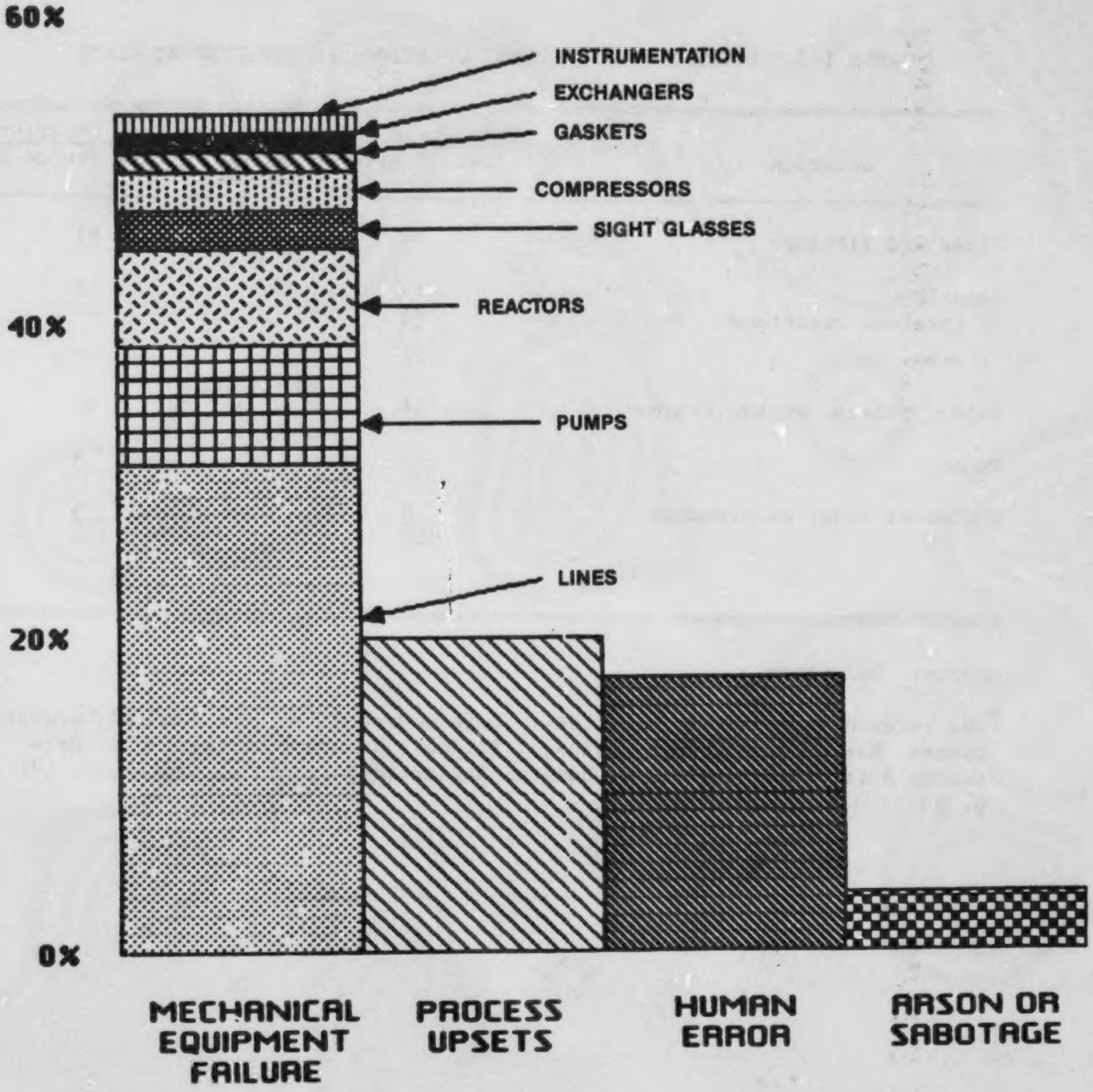


Figure 1-3. Causes of loss in the chemical and allied industries according to insurance survey.

Source: Adapted from Reference 3.

TABLE 1-2. DISTRIBUTION OF EVENT LOCATIONS AS REPORTED BY KLETZ

Location	Percentage Attributable to Each Location[a] (Data Source A)	(Data Source B)
Pipes and fittings	34	61
Vessels	—	9
- internal reactions	22	—
- other	21	—
Relief valves, vents, drains	11	22
Pumps	6	4
Equipment under maintenance	6	4
	100	100

Source: Reference 4.

[a] Two references were cited by Kletz. Data source A is: One Hundred Largest Losses, Marsh and McLennan, Chicago, Illinois, Sixth Edition, 1985. Data source B is: Davenport, J., Chemical Engineering Progress, September, 1977, p. 54.

as each strives to apply the latest knowledge and technology to the prevention and mitigation of accidental toxic chemical releases.

A number of public and private organizations have developed codes and standards, recommended practices, design criteria, or guidelines establishing at least minimum standards for equipment and systems potentially involved in accidental releases. Table 1-3 presents a list of some of these organizations. Some of the codes and standards developed by these organizations present recommended design criteria for individual pieces of equipment or for entire plant systems. Others present recommended practices for conducting a safe operation. Some of these organizations have published specific hazard evaluation and reduction information. A complete presentation of such information is beyond the scope of this manual, but the reader may contact individual organizations for additional information. Table 1-4 summarizes general areas addressed by the various organizations.

1.3 PURPOSE OF THIS MANUAL

The User's Guide is an introduction to the overall area of accidental chemical releases prevention, protection, and mitigation for government agency personnel, industry managers, technical people, and other persons concerned with reducing the risk of accidental toxic chemical releases. It is intended to assist and inform the reader about where and how to seek additional information. The manual is also a guide to the more detailed information in the companion set of manuals and to the general technical literature.

Government agencies will probably continue to become more involved in this area as awareness specific to accidental releases increases and more regulations are promulgated. Past involvement by industry has been broad. Future participation in the area of accidental release prevention, protection, and mitigation is expected to increase in response both to new regulations and to increased awareness of toxic air release issues on the part of company management, technical staff and the general public.

TABLE 1-3. MAJOR ORGANIZATIONS PROVIDING CODES AND STANDARDS, RECOMMENDED PRACTICES, DESIGN CRITERIA, OR GUIDELINES FOR EQUIPMENT IN CHEMICAL AND ALLIED INDUSTRY PROCESS PLANTS

Name	Abbreviation
Technical and Trade Groups	
Air Conditioning & Refrigeration Institute	ARI
Air Moving and Conditioning Association	AMCA
American Association of Railroads	AAR
American Gas Assocation	AGA
American Petroleum Institute	API
American Water Works Association	AWWA
Chemical Manufacturer's Association (formerly Manufacturing Chemists Association)	CMA (MCA)
Chlorine Institute	CI
Compressed Gas Association	CGA
Cooling Tower Institute	CTI
Manufacturers Standardization Society	MSS
National Electrical Manufacturers Association	NEMA
Pipe Fabrication Institute	PFI
Scientific Apparatus Makers Association	SAMA
Society of Plastics Industry	SPI
Steel Structure Painting Council	SSPC
Tubular Exchanger Manufacturers Association	TEMA
U.S. Government Agencies	
Bureau of Mines	BM
Department of Transportation	DOT
U.S. Coast Guard	USCG
Hazardous Materials Regulation Board	HMRB
Federal Aviation Administration	FAA
Environmental Protection Agency	EPA
National Bureau of Standards	NBS
Occupational Safety and Health Administration	OSHA
Testing Standards and Safety Groups	
American National Standards Institute	ANSI
American Society for Testing and Materials	ASTM
National Fire Protection Association	NFPA
Underwriters Laboratories, Inc.	UL
National Safety Council	NSC

(Continued)

TABLE 1-3 (Continued)

Name	Abbreviation
Insuring Associations	
American Insurance Association	AIA
Factory Insurance Association	FIA
Factory Mutual System	FM
Oil Insurance Association	OIA
Professional Societies	
American Conference of Governmental Industrial Hygienists	ACGIH
American Industrial Hygiene Association	AIHA
American Institute of Chemical Engineers	AIChE
American Society of Mechanical Engineers	ASME
Amer. Soc. of Htg. Refrig. & Air-Cond. Engs.	ASHRAE
Illumination Engineers Society	IES
Institute of Chemical Engineers (Britian)	IChE
Institute of Electrical and Electronic Engineers	IEEE
Instrument Society of America	ISA

Source: Adapted from Reference 6.

TABLE 1-4. AREAS COVERED BY CODES, STANDARDS, RECOMMENDED PRACTICES, DESIGN CRITERIA, OR GUIDELINES OF DESIGNATED ORGANIZATIONS (SEE TABLE 1-3 FOR SYMBOLS DEFINITIONS)

Accident Case History	AGA, AIA, AIChE, API, FIA, FM, NFPA, NSC, OIA, OSHA, USCG
Air Compressors	AIA, ANSI, FM, USCG
Air-Fin Coolers	ARI, ASHRAE, OIA, USCG
Boilers	ANSI, NFPA, NSC, UL
Combustion Equipment and Controls	ANSI, FIA, FM, NFPA, NSC, OIA, UL, USCG
Compressors	AIA, ARI, ASHRAE, ASME, FM, OIA, USCG
Cooling Towers	CTI, FM, NFPA, OIA
Drain and Waste Systems	AICHE, AWWA, MCA, USCG
Dust Collection Equipment	FIA, FM, NFPA, USCG
Dust Hazards	ACGIH, AIHA, ANSI, BM, FIA, FM, NFPA, NSC, UL, USCG
Electric Motors	ANSI, IEEE, MCA, NFPA, UL, USCG
Electrical Area Classification	AIA, ANSI, API, FIA, FM, MCA, NFPA, NSC, OJA, OSHA, USCG
Electrical Control and Enclosures	AIA, ANSI, ARI, FIA, FM, IEEE, ISA, MCA, NEMA, NFPA, NSC, OIA, OSHA, UL, USCG
Emergency Electrical Systems	AGA, AIA, FM, IEEE, NEMA, NFPA, USCG
Fans and Blowers	ACGIH, AIHA, AMCA, ARI, ASME, FM, USCG
Fire Protection Equipment	AIA, ANSI, API, AWWA, BM, CGA, FIA, MCA, NEMA, NFPA, NSC, OIA, OSHA, UL, USCG

(Continued)

TABLE 1-4 (Continued)

Fire Pumps	ANSI, FM, HI, IEEE, NFPA, UL, USCG
Fired Heaters	ANSI, ASME, FIA, FM, NFPA, OIA, UL, USCG
Gas Engines	FM, NFPA, OIA, USCG
Gas Turbines	AGA, FIA, FM, NFPA, OIA, USCG
Gear Drives Power Transmission	AGMA, AIA, ANSI, NSC, USCG
Grounding and Static Electrical	AIA, ANSI, API, FIA, FM, IEEE, NEMA, NFPA, NSC, OIA, OSHA, UL, USCG
Inspection and Testing	ABMA, AGMA, AIChE, AMCA, API, ASHRHE, ASTM, AWWA, CGA, CTI, DOT, HEJ, HI, IEEE, MSS, NFPA, NSC, PFI, USCG
Instrumentation	AIA, ANSI, API, ARI, ASTM, AWWA, CGA, FIA, FM, HMRB, IEEE, ISA, NBS, NFPA, OIA, SAMA, UL, USCG
Insulation and Fireproofing	AIA, ANSI, ASHRAE, ASTM, FM, OIA, UL, USCG
Jets and Ejectors	HEI, USCG
Lighting	ANSI, FM, IEEE, IES, NEMA, NFPA, NSC, UL, USCG
Lubrication	AMCA, ANSI, ASME, NFPA
Material Handling	MCA, NFPA, NSC, OSHA
Materials of Construction	AIA, ANSI, ASTM, AWWA, CGA, CI, CTI, FM, HMRB, ISA, MCA, NBS, NFPA, NSC, OIA, TEMA, UL, USCG
Noise and Vibration	AGA, AIChE, AIHA, AMCA, ANSI, API, ARI, ASHRAE, ASTM, EPA, ISA, NFPA, NSC, OSHA, UL

(Continued)

TABLE 1-4 (Continued)

Painting and Coating	AIChE, ANSI, ASTM, AWWA, HMRB, OSHA, NBS, SSPC, UL
Piping Materials and Systems	AGA, AIA, ANSI, API, ARI, ASHRAE, ASTM, AWWA, CGA, CI, FIA, FM, HMRB, IES, MSS, NBS, NFPA, NSC, PFI, SPI, UL, USCG
Plant and Equipment Layout	AAR, AIA, API, AWWA, CGA, FIA, FM, HMRB, MCA, NFPA, NSC, OIA, USCG
Pneumatic Conveying	ANSI, FIOA, NFPA, USCG
Power Wiring	ANSI, API, FIA, FM, IEEE, NEMA, NFPA, OIA, OSHA, UL, USCG
Pressure Relief Equipment Systems	AIA, API, ASME, CGA, CI, FIA, FM,
Pressure Vessels	AIA, API, ASME, CGA, DOT, NFPA, NSC, OSHA, USCG, HMRB, OIA, OSHA, USCG
Product Storage and Handling	AAR, AIChE, AIA, ANSI, API, CGA, CI, FIA, FM, MCA, NFPA, OIA, OSHA, USCG
Pumps	AIChE, ANSI, AWWA, CI, NFPA, OIA, UL, USCG
Refrigeration Equipment	ANSI, API, ASHRAE, FM, NFPA, UL, USCG
Safety Equipment	ACGIH, AIHA, ANSI, BM, CGA, CI, FM, MCA, NSC, OSHA, UL, USCG
Shell and Tube Exchangers	AGA, AIChE, API, ASHRAE, ASME, CGA, PFI, USCG
Shutdown System	AIA, API, FIA, NFPA, OIA, UL, USCG
Solids Conveyors	MCA
Stacks and Flares	FAA, OIA, USCG

(Continued)

TABLE 1-4 (Continued)

Steam Turbines	AIA, FM, IEEE, OIA, USCG
Storage Tanks	AWWA, CI, NBS, NFPA, OIA, OSHA, UL, USCG
Ventilation	ACGIH, AIHA, ANSI, BM, FIA, FM, NFPA, NSC, UL, USCG
Venting Requirements	API, FIA, FM, HMRB, NFPA, USCG

Source: Adapted from Reference 6.

Table 1-5 illustrates the potential needs of government agency personnel and individual companies if called on to enforce or comply with a regulation specifically geared toward accidental release prevention. These needs include the resources that will be required for such a task. The table summarizes approaches to meeting these needs. The User's Guide and companion manuals will provide one information resource for responding to accidental release regulations established by local authorities. For needs or approaches not specifically covered in the manuals, or for areas where more detail is required than the manuals can provide, the references cited in the manuals can help the reader obtain more detailed information.

For both regulators and companies interested in release prevention, an overall concept of a process facility must be developed in terms of the physical and functional areas that would be covered by a complete release prevention evaluation or control plan. Such a concept is shown in Figure 1-4. These aspects of a facility must be addressed at each stage in the total life cycle of the facility.1 The basic stages, design, construction, startup, operation and shutdown, are discussed further in Section 3.4.

Chemicals are transported to the facility and pass through a sequence of transfer, storage, and process operations that produce more chemicals that pass through a similar sequence until they leave the facility. To develop a company hazard control plan or for a regulatory review of such a plan, each step in the sequence must be scrutinized for the following:

- The toxic chemicals used and where,
- Hazardous processes and operations, and
- Control measures.

Later sections of this manual address each of these considerations by summarizing the fundamental principles of chemical hazards, process and operational hazards, hazard identification and evaluation, and hazard control.

TABLE 1-5. EXAMPLES OF NEEDS AND APPROACHES FOR REGULATORS AND COMPANIES ADDRESSED BY PREVENTION REFERENCE MANUALS

Government		Industry	
Needs	Approach	Needs	Approach
Basic Information		Basic Information	
Types of Facilities	Identify facilities within the regulators jurisdiction that are subject to safety concerns covered by the accidental release guidelines or regulations.	Types of Processes	Evaluate the requirements of the accidental release safety objectives, guidelines, or regulations in light of the specific processes in use at the facility.
	Gather historical background on previous accidental releases at each facility and accidental releases at similar facilities.		Gather historical background on previous accidental releases at similar facilities.
Types of Processes	Obtain information about the processes used at each facility.		
Hazard Identification	Become aware of the range of accidental release hazards associated with the processes used at each of the facilities covered by the regulation.	Hazard Identification	Become aware of the range of accidental release hazards associated with the processes used at the facility.
Prioritization	Develop a criteria for ranking the facilities for accidental release risk.		Use hazard identification and evaluation methods to evaluate the adequacy of the accidental release prevention measures already in place and to pinpoint areas of deficiency.
	Compare the available resources to the ranking and select which facilities require further investigation and specifically which processes within a facility should be examined for compliance.		
	Identify the range of potential control techniques that could be applied to each process to be examined.		
Control Measure Verification		Control Measure Selection and Evaluation	
Document Review	Identify which accidental release control techniques are in place at each facility by requesting summary documentation of a control plan.	Prioritization	Identify the control measures that could be applied to the areas where the present control measures are deficient.
	If the documentation provided does not indicate compliance then request additional documentation.		Evaluate the resources that are required to perform each level of control.
			Evaluate the effectiveness of each control method.

(Continued)

TABLE 1-5 (Continued)

Government		Industry	
Needs	**Approach**	**Needs**	**Approach**
Facility Inspection	If the additional documentation does not indicate compliance then visit the facility and perform a detailed review of control plan documentation. If compliance is not confirmed then inspect those portions of the facility that are of interest.		Apply measures that will bring the facility into compliance and will provide the most efficient use of resources. Prepared both detailed and summary documentation of control practices. Periodically reinspect the facility; especially important when process changes are made.
Resources Required/Available		Resources Required/Available	
Historical literature	Newspapers; local news stations.	Historical literature	Newspapers; local news stations.
Technical literature	Loss prevention journal articles and text books; Accidental Release Prevention Reference Manual (ARPRM) series.	Technical literature	Loss prevention journal articles and text books; Accidental Release Prevention Reference Manual (ARPRM) series.
Public records	State or local data base.	Public records	State or local data base.
Organizations	Technical societies and trade organizations; local, state and federal regulatory organizations; consultants.	Organizations	Technical societies and trade organizations; local, state and federal regulatory organizations; consultants.
Regulations	Related regulations that impact accidental release prevention; other regulations that specifically apply to accidental release prevention.	Regulations	Related regulation that impact accidental release prevention; other regulations that specifically apply to accidental release prevention.
Personnel	Experienced personnel within the regulatory agency. Personnel from other regulatory agencies with experience in accidental release prevention. Outside consultants with experience in accidental release prevention.	Personnel	Experienced personnel within the plant. Outside consultants with experience in accidental release prevention.
Costs	The costs the agency will incur by performing document and facility reviews at various levels of detail. The facility's cost to perform different varieties of internal hazard evaluation, the cost to implement various control measures, and the cost of assembling a comprehensive control plan.	Costs	The cost to perform different varieties of internal hazard evaluation, the cost to implement various control measures, and the cost of assembling a comprehensive control plan.

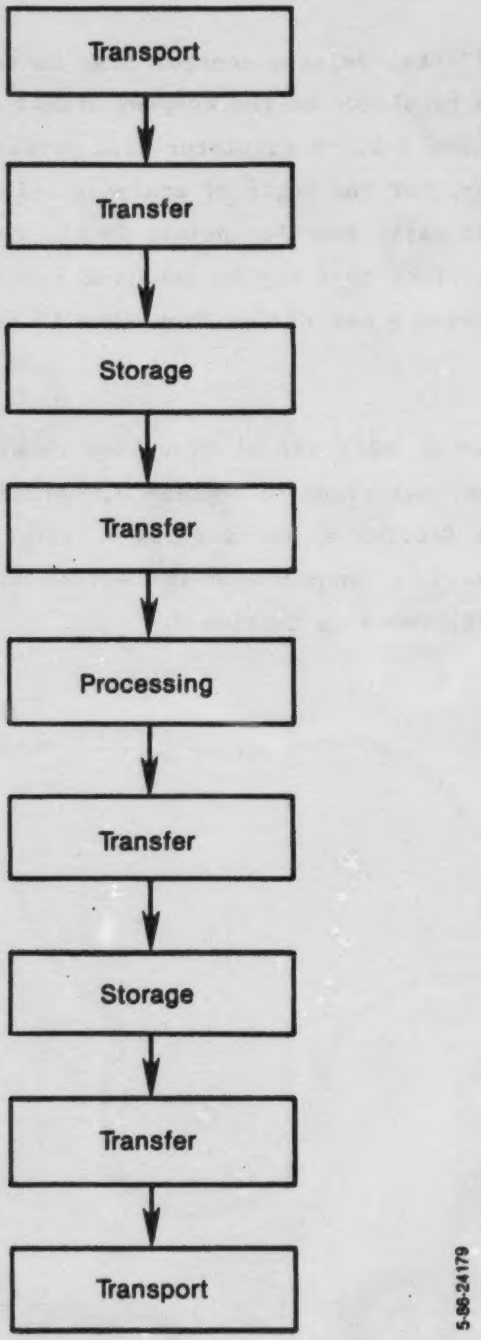

Transport
Transfer
Storage
Transfer
Processing
Transfer
Storage
Transfer
Transport
5-86-24179

Figure 1-4. Functional areas of a typical chemical process facility.

Once an accidental release control plan is developed, the review of the control plan by a regulator or the company itself may follow the kind of logic flow shown in Figure 1-5. A regulator will probably go into less detail than a company reviewer, but the logic of analysis will probably be the same. This diagram highlights major decision points in the review process and illustrates the possible iterations that may be involved before a plan can be considered acceptable. Procedures may differ from this in detail in individual circumstances.

The remainder of this manual discusses chemical hazards in Section 2, hazards in process operations in Section 3, methods for hazard identification and evaluation in Section 4, an overview of principles of control in Section 5, a guide to facility inspections in Section 6, costs of prevention in Section 7, and references in Section 8.

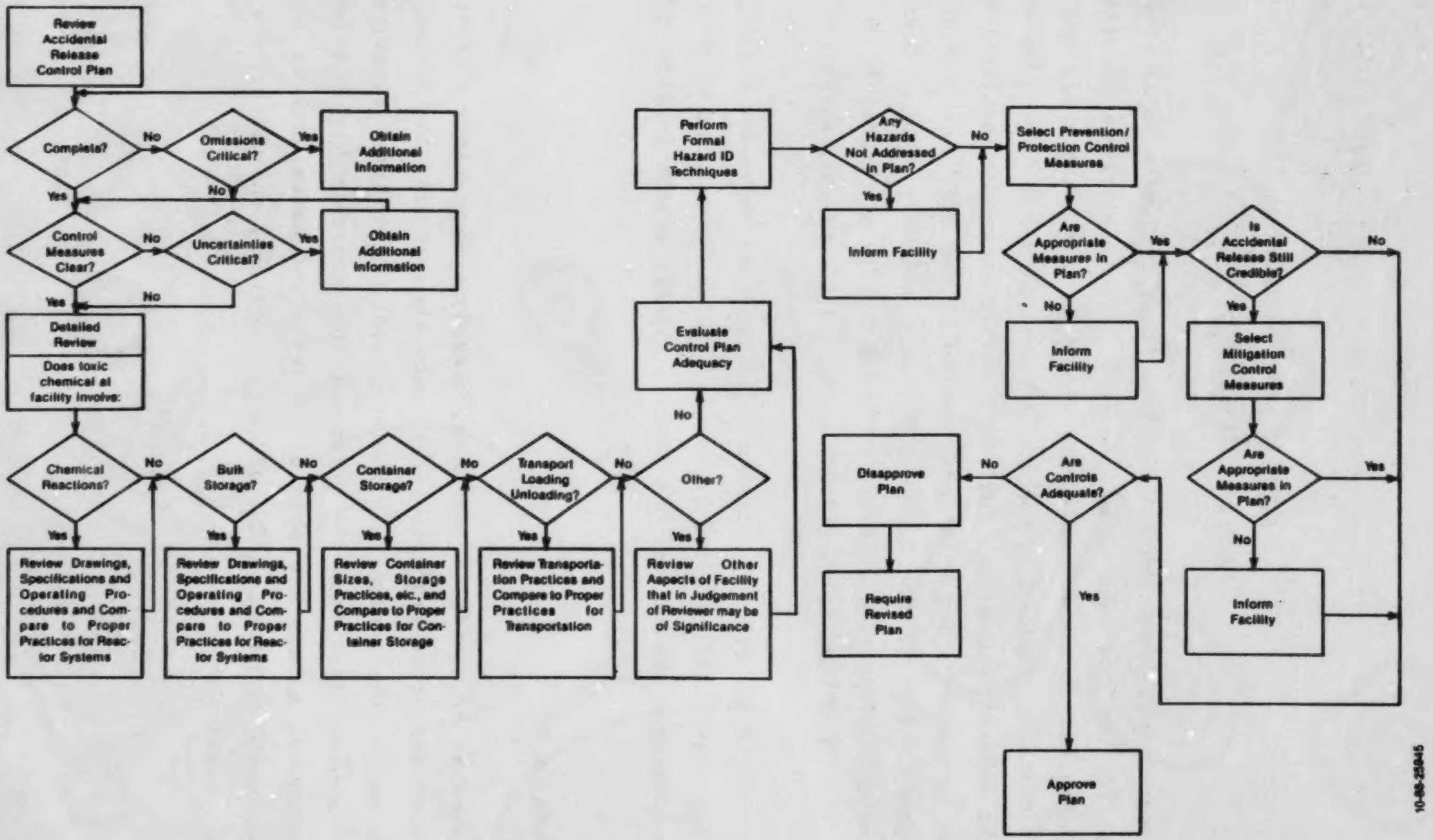

Review Accidental Release Control Plan
Complete?
No
Omissions Critical?
Yes
Obtain Additional Information
No
Yes
Control Measures Clear?
No
Uncertainties Critical?
Yes
Obtain Additional Information
No
Yes
Detailed Review
Does toxic chemical at facility involve:
Chemical Reactions?
Yes
Review Drawings, Specifications and Operating Procedures and Compare to Proper Practices for Reactor Systems
No
Bulk Storage?
Yes
Review Drawings, Specifications and Operating Procedures and Compare to Proper Practices for Reactor Systems
No
Container Storage?
Yes
Review Container Sizes, Storage Practices, etc., and Compare to Proper Practices for Container Storage
No
Transport Loading Unloading?
Yes
Review Transportation Practices and Compare to Proper Practices for Transportation
No
Other?
Yes
Review Other Aspects of Facility that in Judgement of Reviewer may be of Significance
No
Evaluate Control Plan Adequacy
Perform Formal Hazard ID Techniques
Any Hazards Not Addressed in Plan?
Yes
Inform Facility
No
Select Prevention/ Protection Control Measures
Are Appropriate Measures in Plan?
No
Inform Facility
Yes
Is Accidental Release Still Credible?
No
Yes
Select Mitigation Control Measures
Are Appropriate Measures in Plan?
Yes
No
Inform Facility
Are Controls Adequate?
No
Disapprove Plan
Require Revised Plan
Yes
Approve Plan
10-88-25945

Figure 1-5. Example of logic flow for accidental release control plan review.

SECTION 2

CHEMICAL HAZARDS

A fundamental need from either a regulator's or company's point of view is the identification and ranking of chemical hazards within a process facility. The primary basis for selecting chemicals that pose a significant danger if accidentally released is their acute toxicity, but other properties also enter the selection process. Various lists of hazardous chemicals have been prepared by numerous organizations, including the U.S. Environmental Protection Agency (EPA) and the European Economic Community (EEC). Current hazardous chemicals of primary interest to the U.S. EPA are listed in an EPA publication (5). This list is reproduced in Appendix A of this manual.

This section of the manual discusses major considerations for identifying and classifying toxic chemicals and serves as a guide for setting up priority lists of the chemicals themselves. An example ranking system is also illustrated.

2.1 TOXIC CHEMICALS

In the context of accidental releases, hazardous chemicals are materials with acute toxic and other properties that make them an imminent threat to human health and/or the general environment, even after brief exposure. Releases of chemicals that have the potential for long-term health effects and/or environmental damage are also of concern, and while many of the principles discussed in this manual would apply to these, the primary focus is on acute toxic chemicals.

The primary methods of expressing toxicity are:

- Immediately Dangerous to Life and Health (IDLH), defined as the maximum level to which a healthy male worker can be exposed for 30 minutes and escape without suffering irreversible health effects or impairing symptoms. These values have been developed and specified by the National Institute for Occupational Safety and Health (5).

- Low Lethal Concentration (LC_{LO}) is the lowest lethal concentration observed in tests on laboratory animals or in accidental human exposure.

- 50% Lethal Concentration (LC_{50}) is the concentration for which 50% of the test animals died when exposed for a specified period of time.

- Permissible Exposure Limit (PEL), defined as the maximum air concentration to which a healthy male worker can be exposed for 8 hours per day, 40 hours per week without adverse effects as determined by the Occupational Safety and Health Association (OSHA).

- Short-term Exposure Limit (STEL) is the maximum concentration to which workers can be exposed for up to 15 minutes, provided no more than four exposures per day are permitted with at least 60 minutes between exposure periods.

The relative acute toxic hazard of different chemicals may be ranked using any one of these criteria. In a recent document, the U.S. EPA suggests using the IDLH as the primary criterion for estimating consequences of accidental releases, with the LC_{LO} and LC_{50} as second and third choices, or other criteria if these are not available (5).

The ultimate adverse consequences of a release result from the toxicity of the chemical, but other physical and chemical properties are also important when considering the causes and prevention of releases, and their consequences.

2.2 PHYSICAL AND CHEMICAL PROPERTIES

Significant physical and chemical properties include boiling point, vapor pressure, heat of vaporization, density, viscosity, and reactivity. Low boiling points and high vapor pressures increase the quantity of chemical emitted to the air during a release. A low heat of vaporization results in an increased rate of vaporization from spills or liquid releases of volatile toxic chemicals. High vapor or gas densities hinder dispersion and result in low lying clouds which imperil people at ground level. In the case of liquids, viscosity is important because a spilled or leaked low viscosity material will flow and spread more rapidly than a high viscosity material. Other physical properties, also significant in the evaporation and dispersion behavior of liquids, vapors, and gases, include surface tension, diffusivity, and heat capacities. For solids, particle size is important. Reactivity includes properties such as flammability, explosivity, exothermicity, and corrosiveness.

Flammability is the ability of a chemical to burn. Explosivity is the ability of a chemical to react rapidly enough with itself or other materials including oxygen in ambient air, to cause an explosion. A common destructive manifestation of reaction with air is a vapor cloud or dust explosions when a material is within its explosive limits. Exothermicity refers more to specific chemical reactions than to the chemicals themselves, but this ability for the reactions to generate significant amounts of heat means that if they get out of control, they can result in thermal runaway, overpressure in containment equipment, and possibly to explosions. Finally, corrosiveness, another aspect of reactivity, can damage equipment and cause equipment failures and chemical releases. A more detailed discussion of the relationship between specific chemical properties and release hazards can be found in the technical literature (1, 6).

Vapor pressure, vapor density, and the IDLH are the minimum property data needed to establish that a specific chemical is an acute toxic, air release hazard. Values for some common hazardous chemicals are presented in Table 2-1.

TABLE 2-1. SELECTED PROPERTIES OF SOME COMMON HAZARDOUS CHEMICALS

Chemical	Boiling Point °F	Vapor (psi) Pressure 68°F	Vapor Density (Air = 1) 32°F	IDLH (ppm)
Ammonia	-28.03	128.9	0.597	500
Carbon Tetrachloride	170.1	1.74	5.32	300
Chlorine	-29.29	92.8	2.49	25
Chloropicrin	233.6	0.35	5.70	4
Anhydrous Hydrogen Chloride	-121.1	0.505	1.27	100
Anhydrous Hydrogen Fluoride	67.10	15.0	1.56	20
Phosgene	45.46	23.5	3.40	2
Sulfur Dioxide	13.96	47.9	2.26	100
Hydrogen Cyanide	78.26	12.8	0.95	50

Sources of data: References 7, 8, 9, 10 and 11.

Table 2-2 shows a more complete list of properties as would be required for a complete comparative evaluation of chemicals.

Once the chemicals of concern have been identified, the next step in controlling accidental releases is to examine the operations in which these chemicals are used. Hazards in process operations is the subject of the next section of this manual.

TABLE 2-2. CHEMICAL PROPERTY DATA PERTINENT TO ACCIDENTAL RELEASE EVALUATIONS

- Chemical name, synonyms, and Chemical Abstracts Service Registry Number (CAS #)
- Chemical formula and/or drawing of structure
- Phase at room temperature
- Boiling point (normal and/or at _____ pressure)
- Melting point
- Liquid density and/or specific gravity at _____ temperature
- Vapor pressure at _____ temperature(s) (e.g., Antoine equation)
- Gas density and/or specific gravity at _____ temperature
- Solubility in water, alcohol, ether, and other reactants/products
- Liquid viscosity
- Enthalpy at _____ temperature(s)
- Specific heat at constant volume
- Specific heat at constant pressure
- Critical temperature
- Critical pressure
- Critical volume
- Flash point
- Limits of flammability and explosivity
  - NEPA 704M Safety Hazard Rating (health, flammability, reactivity, special)
- Differential thermal analysis
  - CHETAH (Chemical Thermodynamics and Hazards) evaluation (or equivalent)

Hazard Properties:
- Contact Poison
- Inhalation Irritant
- Carcinogen
- Releases Vapors
- Oral Poison
- Lachrymator
- Pyrophoric
- Mutagen
- Hyroscopic
- Inhalant Poison
- Contact Irritant
- Teratogen

Reaction Properties:
- Reacts with Acids
- Exothermic
- Solidifies
- Reacts with Metals
- Decomposes
- Reacts with Air
- Reacts with Bases
- Releases Gases
- Violent Reaction
- Polymerizes
- Light Sensitive
- Reacts with Water
- Reacts with Alkanes
- Foams
- Forms Toxic Products
- Autocatalytic
- Shock Sensitive

SECTION 3

HAZARDS IN PROCESS OPERATIONS

Once a regulator or company has identified the toxic chemicals manufactured, used, or stored at a facility, the process situations that could lead to a release should be identified so that the adequacy of proposed controls (in the case of the regulator), or select appropriate control measures (in the case of the company) can be evaluated. Before identifying process hazards, discussed in Section 4, and their corresponding control measures for specific facilities, discussed in Section 5, an understanding of the kinds of hazards, and available control measures is required.

This section of the manual presents an overview of hazards and failure modes of process systems for toxic chemicals as they relate to process design considerations, physical plant design considerations, and operational procedures and practices at any stage in the life cycle of a facility. Examples of specific hazards and possible causes are cited for each of these key areas.

3.1 BACKGROUND

The preceding sections have presented an overview of accidental releases. The hazard of a release increases with the toxicity and reactivity of the chemicals involved, the process energy content, the inventory, and the complexity of the process system. The more toxic a material, the more severe may be the consequences of release. Reactive materials are more dangerous than less reactive materials because physical containment may be more difficult (e.g., corrosion problems), and operational problems may be more severe (e.g., hard to control rapid chemical reaction). Operating pressure and temperature determine process energy content. The higher the energy content, the higher the potential driving force for release and the more difficult it is to design the containment equipment. Large inventories are a greater hazard than small inventories because more material can be released. The more complex a process is, the more physical components there are that can fail, making control more difficult. These broad categories of hazards must be addressed in the safe design, construction, and operation of process systems for toxic chemicals.

They can be addressed in the following general categories:

- Process design considerations;
- Physical plant design considerations; and
- Operational procedures and practices.

Each of these categories organizes specific hazards, failure modes, and control measures in terms of prevention, protection, and mitigation. Examples of specific hazards and failure modes are discussed in this section. Prevention, protection, and mitigation control measures are discussed in Section 5.

Basic causes of releases can be summarized as follows:

- Process or operational failures causing pressure or temperature to exceed limits of the process equipment;

- Equipment containment failures at normal process conditions;

- Operational or maintenance errors, omissions, or deliberate criminal acts (e.g., vandalism) leading to either of the above two conditions, or to direct releases (e.g., inadvertently opening a valve and releasing material); and

- Imposition of external damaging factors such as fire, explosion, flooding, or mechanical stress, which directly lead to equipment failure. Natural phenomena such as flooding, earthquakes, or wind storms can be contributing factors here.

Each of these general causes can have many specific initiating and enabling events or contributing causes, forming a chain leading to the final event which physically results in the release. Prevention and protection measures interdict the event chain at a point before the final release event can occur.

Some specific areas of process facilities that should always receive close attention are:

- Large inventories of toxic materials such as storage areas, and inventories of flammable or explosive materials near large toxic inventories,
- Exothermic chemical reactors, and inventories of chemicals prone to exothermic reactions with other materials, even if by contamination rather than by design,
- Any process areas with high energy content; high temperature and pressure operations,
- Any process operations with positive energy input such as distillation,
- Processes with complex sequencing or unit operations interactions such as recycles,
- Processes involving toxic chemicals in combination with highly corrosive, flammable, or explosive materials, and

- Existing process facilities that have recently been modified, are very old, or very new.

There are many other specific areas that can be listed, but the above represent areas of high priority.

Table 3-1 presents examples of a few typical process hazard areas and possible corresponding control technologies. Other hazard areas and corresponding controls could be listed.

3.2 PROCESS DESIGN CONSIDERATIONS

Process design considerations encompass technology, procedures and practices associated with the sequence and conditional state of all of the process steps and operations in a chemical process. These considerations include the nature of the chemical materials used in the process and the fundamental manipulated process variables. Process design considerations address the relationships between physical variables and time; in other words, the physical states of the process as a function of time and the means and characteristics of process control. Process design considerations include:

- Process characteristics and chemistry,
- Overall process control,
- Flow control,
- Pressure control,
- Temperature control,
- Quantity control,
- Mixing effects,
- Composition control,
- Energy systems,
- Detection and alarm systems, and
- Fire and explosion protection.

TABLE 3-1. SOME TYPICAL PROCESS HAZARD AREAS AND EXAMPLES OF CORRESPONDING CONTROL TECHNOLOGIES

Hazard Area	Example Control Technologies
Large inventories of toxic materials	• Change process or procedures to reduce need for large inventories. • Use substitute. • Design storage for higher containment reliability.
Exothermic chemical reactors	• High reliability cooling systems, including backup cooling. • Change process chemistry. • High reliability feed process control. (e.g., feed interlocks, ratio control) • Emergency relief systems. • Emergency dump systems. • Emergency quench and inhibition systems.
Contamination of stored chemicals	• Special backflow protection. • Special isolation valves. • Equipment/process segregation.
Distillation processes	• High reliability process control. • Venting and pressure relief to emergency scrubbers or flares. • High reliability heating systems, with emergency shutdown interlocks. • Distillation under vacuum.

Process failures leading to an accidental release may be related to deficiencies in any of these areas. Such failures would cause the conditional state of the system to exceed the design limits of the equipment or the ability of a human operator to respond quickly or accurately enough to maintain control for changes that are occurring in the process . For example, the loss of flow control of a reactant to an exothermic chemical reactor could lead to a loss of temperature control, which, in turn, could cause overpressure (loss of pressure control). This could lead to a vessel rupture. If events occurred fast enough, a human operator might not be able to detect and respond quickly enough to take corrective action.

Some examples of specific hazards associated with each of these considerations include:

- Process characteristics and chemistry--potential explosive mixtures, or highly exothermic reactions;
- Overall process control--a control system which is improperly configured for the dynamics of the process, causing sensitivity and difficult-to-control conditions;
- Flow control--significant deviations such as insufficient cooling water rates, excessive reactant feeds, or blockage;
- Pressure control--overpressure or severe cycling or surges;
- Temperature control--overheating equipment to the point of materials failure or runaway chemical reactions;
- Quantity control--incorrect sequence of reactant charge, incorrect reactant ratio, or overfilling a vessel;

- Mixing--inadequate mixing causing poor heat transfer and overheating;

- Composition--contamination leading to unexpected reactions or corrosion;

- Energy systems--loss of critical heating or cooling;

- Detection and alarm systems--inadequacy or instrument failure;

- Fire and explosion protection--inadequacy or equipment failure.

Details of hazards associated with each of these areas will be discussed in a companion manual on prevention and protection control technologies, in this series.

3.3 PHYSICAL PLANT DESIGN CONSIDERATIONS

As stated earlier, a release may result from the conditional state of the process exceeding the physical limits of the equipment, or at normal process conditions when the physical limits of the equipment deteriorate below those required for containment. In either case, equipment will fail. Physical plant design considerations address both situations, as well as the interactions of individual equipment failures with failure of the total system.

Physical plant design considerations include the following:

- Codes and standards,
- Complexity and operability,
- Reliability,
- Materials of construction,

- Vessels (e.g. heat exchanger columns, tanks, and reactors),
- Piping and valves,
- Process machinery,
- Instrumentation, and
- Siting and layout.

Design must ensure that equipment and components can withstand normal operating conditions for the anticipated life of the facility and can tolerate abnormal conditions within certain bounds. A common cause of failure is the deterioration of equipment over time through various materials failure phenomena such as corrosion. Codes and standards provide some basis for ensuring adequate design, but these are primarily minimum standards. In specific cases, design beyond these minimum standards may be important. The complexity and operability of the equipment may also influence how well a process is controlled, and how easily the equipment and its components are maintained. Reliability, the ability of equipment and components to perform their functions with few or no failures, depends on adequate design, construction, and maintenance. A fundamental principle of reliability is that the system will be only as reliable as its most unreliable component, which is the basis for backup or redundancy in physical systems.

Specific causes of failure have been classified in the technical literature (1). Some common causes of mechanical failure are:

- Excessive stress,
- External loading,
- Overpressure,
- Overheating,
- Mechanical fatigue and shock,
- Thermal fatigue and shock,
- Brittle fracture,
- Creep, and

- Chemical attack (e.g., corrosion, hydrogen blistering, etc.)

Conditions leading to such failure modes range from improper design through improper installation and operation. For example, improper alignment can lead to excessive stress on couplings or shafts of rotating equipment. If properly recognized and evaluated, the prevention of each of these failure modes can be incorporated into initial facility design and construction. The first line of prevention of such failures is in the proper selection and use of construction materials. As can easily be seen, however, some of these conditions are related to operating conditions which can change over time.

Recognition of these failure modes is the basis for many of the specific equipment considerations for the categories of vessels, piping and valves, process machinery, and instrumentation. The manual on control technologies will address these considerations in more detail.

Siting and layout are also considered to be within the realm of physical plant design considerations. Hazards associated with siting may include both natural and man-made factors. Some natural factors include floods, earthquakes, and windstorms. Man-made factors include the siting of facilities near other high hazard facilities, or in areas where an adequately educated and trained labor force may not be available. Layout considerations refer to the relationships among equipment and components within a process unit and among process units in an overall facility. Hazards can arise from layout, for example, when highly toxic and flammable materials or incompatible reactive materials are stored close together.

In summary, physical plant design considerations are concerned with the hardware, as opposed to process design considerations, discussed earlier, which are concerned with the "software" of a process facility.

3.4 PROCEDURES AND PRACTICES

The final general hazard area in process operations involves procedures and practices. Hazards in this area arise from human error in decision making, physical actions controlling a process, and in planning, supervising, and other non-physical activities in the design, construction, and operation of process facilities at any stage of a facility's total life cycle. Figure 3-1 illustrates the various phases of a facility life cycle where errors leading to hazards may be introduced. Figure 3-2 illustrates some kinds of errors that may be introduced. The realization of some hazards in this area are indirect; for example, a lax management policy that does not enforce its own safety standards. Others are direct, such as the operator who takes a wrong action at a control panel.

One categorization of procedures and practices includes:

- Management policy,
- Operator training and practices,
- Maintenance practices, and
- Communications.

Management policy is important because the successful prevention of accidental releases requires the commitment of the human, financial, and material resources of an organization to do what is necessary for release prevention. One of the most important roles of management, after an appropriate safety policy has been established, is to enforce it, keep it up to date, and change it as circumstances change. For example, a preventive maintenance program for high hazard process areas may be well defined and properly written up, but if the program is not audited to see that it really works, then the program may not accomplish its objective. The focus on loss prevention can be so much on specific details that the indirect problem of poor management or supervision in failing to create a proper safety environment is overlooked. Management policy should address special safety procedures for toxic chemicals

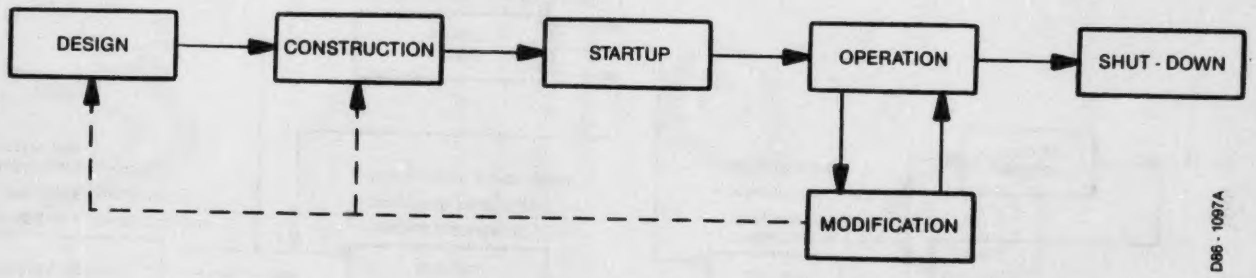

DESIGN
CONSTRUCTION
STARTUP
OPERATION
SHUT - DOWN
MODIFICATION
D86 - 1097A

Figure 3-1. Major phases of facility life cycle.

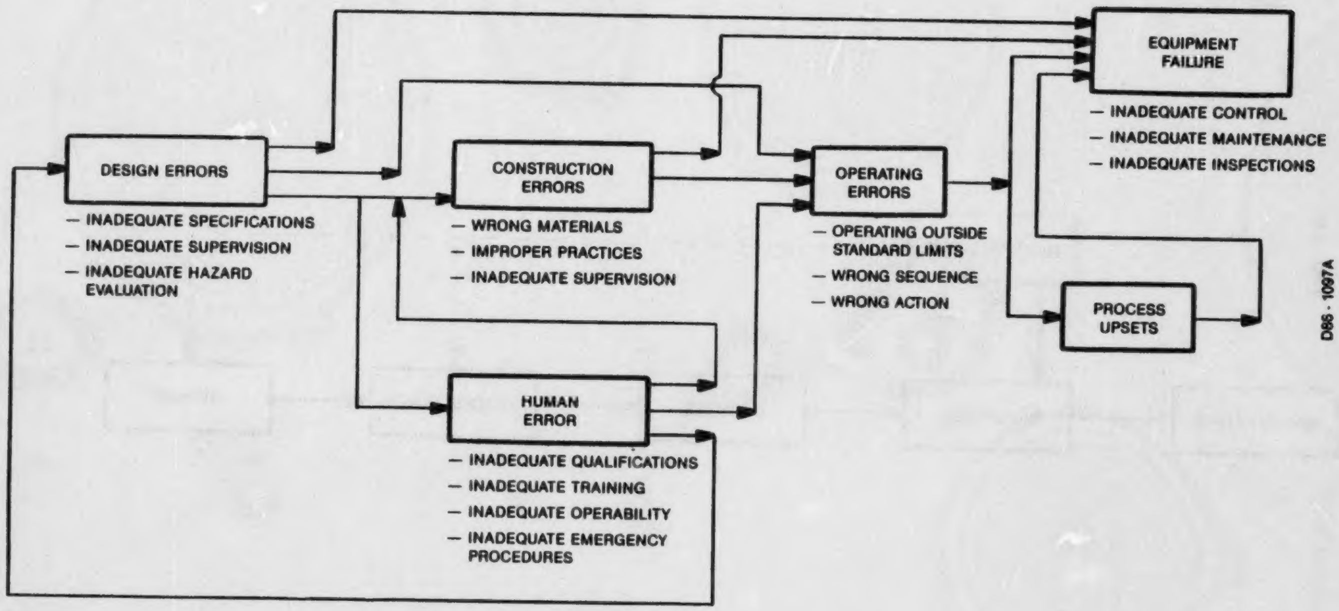

DESIGN ERRORS
— INADEQUATE SPECIFICATIONS
— INADEQUATE SUPERVISION
— INADEQUATE HAZARD EVALUATION
CONSTRUCTION ERRORS
— WRONG MATERIALS
— IMPROPER PRACTICES
— INADEQUATE SUPERVISION
HUMAN ERROR
— INADEQUATE QUALIFICATIONS
— INADEQUATE TRAINING
— INADEQUATE OPERABILITY
— INADEQUATE EMERGENCY PROCEDURES
OPERATING ERRORS
— OPERATING OUTSIDE STANDARD LIMITS
— WRONG SEQUENCE
— WRONG ACTION
EQUIPMENT FAILURE
— INADEQUATE CONTROL
— INADEQUATE MAINTENANCE
— INADEQUATE INSPECTIONS
PROCESS UPSETS
D86 · 1097A

Figure 3-2. Types of errors leading to hazards.

through all parts of the chemical process life cycle that was shown in Figure 3-1.

Operator training and practices have a more direct bearing on release prevention. The skill and knowledge of the operators should be commensurate with the needs of the process, and high hazard processes should, therefore, require a higher standard of operator skill and knowledge than low hazard processes. An often overlooked aspect of operator training is performance auditing. Performance auditing requires a systematic way of obtaining a measurable check on individual operator knowledge is necessary, and especially the operator's knowledge of the possible causes of and means of dealing with unlikely yet potentially serious accidental release events. Emergency response plan drills should be a regular part of operator training.

Maintenance practices are crucial to accidental release prevention. Even if a process facility is originally designed in a way that minimizes the potential for accidental releases, both deliberate and unrecognized changes may occur over time that render a facility unsafe. Proper maintenance is the primary prevention measure that ensures that the original specifications are adhered to and that all special preventive or protective systems are functional.

Finally, the whole human component of accidental release prevention is tied together by effective communications. Information transmitted among the various parts of the organization must be clear, accurate, and timely. Communications procedures for high-hazard facilities should receive high attention and may require different approaches from more routine communications.

A more detailed discussion of each of these areas will be found in the manual on control technologies.

SECTION 4
METHODS FOR HAZARD IDENTIFICATION AND EVALUATION

Hazard identification is the first step in controlling hazards; the evaluation of hazards follows. Hazard identification is qualitative; hazard evaluation is quantitative. Evaluation seeks to determine the relative importance of two different hazards identified and in some cases the relative probability that a specific hazard will be realized. Various formal and systematic methods for both hazard identification and evaluation are used for facilities manufacturing, using, or storing toxic chemicals.

This section of the manual presents general descriptions of the various methods of formal hazard identification and identifies key features of each of these methods including: the purpose, best times to use, nature of the results, staff size required, and the relative cost. Also discussed are the various methods of hazard evaluation and the purpose they serve in the various steps of the hazard evaluation process.

These methods or variations of them are applicable for use by both regulators and companies. The regulator needs to be familiar with them in order to evaluate their appropriateness, interpret results presented by companies who use the methods, and recommend methods to companies who don't. In some cases a regulator may actually use a technique directly to verify a company's analysis. The company needs to be familiar with the techniques in order to identify, analyze, and control hazards.

4.1 HAZARD IDENTIFICATION

The preceding section summarized where hazards can arise in process operations. The first step in hazard control is hazard identification in a specific process or facility. A publication of the American Institute of

Chemical Engineers (AIChE) on guidelines for hazard evaluation lists the following methods of formal hazard identification (12):

- Checklists,
- Safety Review,
- Relative Ranking,
- Preliminary Hazard Analysis,
- What-If Analysis,
- Hazard and Operability Studies,
- Failure Modes, Effects, and Criticality Analysis,
- Fault Tree Analysis,
- Event Tree Analysis,
- Cause Consequence Analysis, and
- Human Error Analysis.

A summary table of key features of these methods is presented in Table 4-1.

The Chemical Manufacturer's Association confirmed the use of these methods in a survey of 39 companies (13). "What-If" analyses and Hazard and Operability (HAZOP) studies were named as the top two methods.

In general, hazard identification procedures can be divided into four main classes:

- Experience,
- Augmented experience,
- Analytical methods, and
- Creative methods.

The experience method compares a new process or equipment situation with knowledge gained from previous experience with similar processes. This method is an inherent part of the principles of design standards and codes, so that hazard identification consists of identifying where deviations from

TABLE 4-1. SUMMARY OF KEY FEATURES OF HAZARD IDENTIFICATION AND EVALUATION METHODS

METHOD	Checklist	Safety Review	Relative Ranking (Mond)
PURPOSE	Identify common hazards Ensure compliance with prescribed procedures	Identify hazards Ensure compliance with prescribed procedures Ensure compliance with design intent. Identifies possible changes Determines applicability of new technology to existing hazards Reviews adequacy of safety maintenance	Provide relative process ranking by risk
WHEN TO USE	Design Construction Startup Operation Shutdown	Startup Operation (i.e., existing facility) Shutdown	Design Operation
NATURE OF RESULTS	Qualitative	Qualitative	Relative qualitative ranking
STAFF SIZE	Small	Small - Moderate	Moderate
RELATIVE COST	Low	Low - Moderate	Moderate

(Continued)

TABLE 4-1. (Continued)

METHOD	Preliminary Hazard Analysis	What If Analysis	HAZOP
PURPOSE	Identify hazards early in process life cycle prior to final plant design	Identify hazards Identify event sequences Identify possible methods of risk reduction	Identify hazards Identify operability problems Identify event sequences Identify possible methods of risk reduction
WHEN TO USE	Early design	Process development Pre-startup Operation	Late design Operation
NATURE OF RESULTS	Qualitative	Qualitative	Qualitative
STAFF SIZE	Small	Small - Moderate	Moderate - Large
RELATIVE COST	Low	Moderate	Moderate - High

(Continued)

TABLE 4-1. (Continued)

METHOD	Failure Modes, Effects and Criticality Analysis	Fault Tree Analysis
PURPOSE	Identify system/equipment failure modes Identify effect of failure on system/plant Rank criticality of each failure mode	Determine causes and event sequence leading to a defined event Identify combinations of causes including both equipment failures and human errors
WHEN TO USE	Design Construction Operation	Design Operation
NATURE OF RESULTS	Qualitative Quantitative for relative ranking of equipment failures	Qualitative Quantitative
STAFF SIZE	Small	Small - Large
RELATIVE COST	Low - Moderate	Low - High

(Continued)

TABLE 4-1. (Continued)

METHOD	Event Tree Analysis	Cause-Consequence Analysis	Human Error Analysis
PURPOSE	Determine consequences sequence of defined initiating event	Identify both cause sequences and consequence sequences of events	Identify potential human errors Identify effects of human errors Identify cause of human errors
WHEN TO USE	Design Operation	Design Operation	Design Construction Operation
NATURE OF RESULT	Qualitative Quantitative	Qualitative Quantitative	Qualitative
STAFF SIZE	Small - Large	Small - Large	Small
RELATIVE COST	Low - High	Low - High	Low

established safe procedures exist, based on experience. Basically the experience method relies on comparing a new situation to a known past situation.

The augmented experience method relies on various checks on design and operation beyond mere comparison to standards or previous situations. As indicated by the previous list, the "What-If" method appears to be one of the most commonly used. Each step of a process is reviewed to determine what would happen following equipment failures, process upsets, or operating errors.

The analytical approach uses either logic diagrams or various types of checklists. Logic diagrams include fault trees, event trees, and cause-consequences diagrams. Logic diagrams clearly define cause-effect relationships and identify combinations of failure that can lead to an undesirable event. These methods can be combined with quantitative data on probabilities to provide a method of hazard evaluation.

These summary descriptions are based on more detailed descriptions presented in the AIChE publication cited previously (12). These methods are also highlighted in some AIChE short courses presented at national meetings. A general description of each hazard identification method follows. These same methods apply for hazard evaluation as discussed in Section 4.2 of this manual.

4.1.1 Checklists

A checklist is a set standard evaluation elements for equipment, materials, or procedures in a chemical process facility. Its purpose is to identify standard hazards at any time in the life cycle of a chemical process from research and development through shut-down. In its most basic configuration, a checklist is merely a memory aid that helps the evaluator remember all the items he should consider. If the checklist is prepared based on pooled corporate or industry experience, it becomes a vehicle for transferring a broader experience base to the evaluator. The level of detail varies with the situation.

4.1.2 Safety Reviews

In the context of accidental releases, a Safety Review is a comprehensive facility inspection to identify facility conditions or procedures that could ultimately lead to a toxic chemical release. This technique is applicable to operating facilities, pilot plants, laboratories, storage facilities, or support functions.

4.1.3 Dow and Mond Hazard Indices

The Dow and Mond Indices are quantitative methods for developing a relative hazard ranking for different chemical processes facilities. Various characteristics of a facility are assigned scores. Features which can lead to an accident are given a negative score and features that can prevent or mitigate the effects of an accident are given positive scores. Scores are combined to yield a ranking index for the process facility being evaluated.

4.1.4 Preliminary Hazard Analysis

The Preliminary Hazard Analysis (PHA) is a hazard identification method for use in the preliminary phase of plant development. The purposes of the PHA are early identification of potential hazards for design and process development personnel. Its special applicability is for the early phases of new processes where there is little past experience. A list of hazards is developed which is used to develop safety guidelines and criteria to be followed as design and development progress.

4.1.5 "What If" Method

A "What If" analysis systematically considers the consequences of unexpected abnormal events that may occur in a process facility. It can include design, construction, operating, or other deviations from the norm. This examination can include all parts of a process facility. Its comprehensiveness and success depends on the experience level of the staff conducting the analysis.

4.1.6 Hazard and Operability (HAZOP) Studies

A HAZOP study can identify process hazards and operability problems. A HAZOP study involves the multidisciplinary team that works together by searching for deviations from expected design and operating conditions. The team carefully examines the process facility stream by stream, or component by component using standard design "guide words." Consequences of deviations are examined using the guide words. Example guide words are presented in Table 4-2.

4.1.7 Failure Modes, Effects, and Criticality Analysis

Failure Modes, Effects, and Criticality Analysis (FMECA) examines the ways in which a process system or its equipment could fail, consequences of failure, and the estimated failure probabilities. FMECA is not efficient for identifying interactions of combinations of equipment failures that lead to accidents because it considers each failure individually and traces its consequences. Criticality rankings can be expressed as probabilities or by various ranking scores based on evaluators' experience.

TABLE 4-2. EXAMPLE GUIDE WORDS AND CORRESPONDING DEVIATIONS FOR HAZOP ANALYSIS

Guide Word	Deviations
None	No forward flow when there should be, i.e., no flow or reverse flow
More of	More of any relevant physical property than there should be, e.g., higher flow (rate or total quantity), higher temperature, higher pressure, higher viscosity, etc.
Less of	Less of any relevant physical property than there should be, e.g., lower flow (rate or total quantity), lower temperature, lower pressure, etc.
Part of	Composition of system different from what it should be, e.g., change in ratio of components, component missing, etc.
More than	More components present in the system than there should be, e.g., extra phase present (vapor, solid), impurities (air, water, acids, corrosion products), etc.
Other than	What else can happen apart from normal operation, e.g., startup, shutdown, uprating, low running, alternative operation mode, failure of plant services, maintenance, catalyst change, etc.
Reverse	Variable or activity is reverse of what it should be, e.g., reverse flow.

4.1.8 Fault Tree Analysis

Fault Tree Analysis (FTA) is a method that constructs a logic tree of events leading to a specifically defined failure event, the "top event." FTA seeks to develop the chain of interrelated events that can lead to a top event. These chains of events include equipment failures and human errors.

The FTA results in identification of combinations of equipment and human failures that are sufficient to result in the top event. The minimum number of independent combinations that can cause the top event are known as minimal cut sets. Probabilities can be assigned to events and the top event probability determined by Boolean algebra.

4.1.9 Event Tree Analysis

An Event Tree Analysis is similar to a FTA except that the logic is to trace the consequences of an initiating event forward to its ultimate consequence. Rather than beginning with the definition of the top event, the event tree finds the top events resulting from initiating and propagating events. A quantitative evaluation can be developed using probabilities in the same manner as with fault trees. The event tree defines multiple consequences of an initial event, whereas a fault tree identifies multiple causes of a final event.

4.1.10 Cause-Consequence Analysis

Cause-consequence analysis combines characteristics of both event tree analysis and fault tree analysis. A cause consequence analysis logically relates both multiple consequences and multiple basic causes or initiating events.

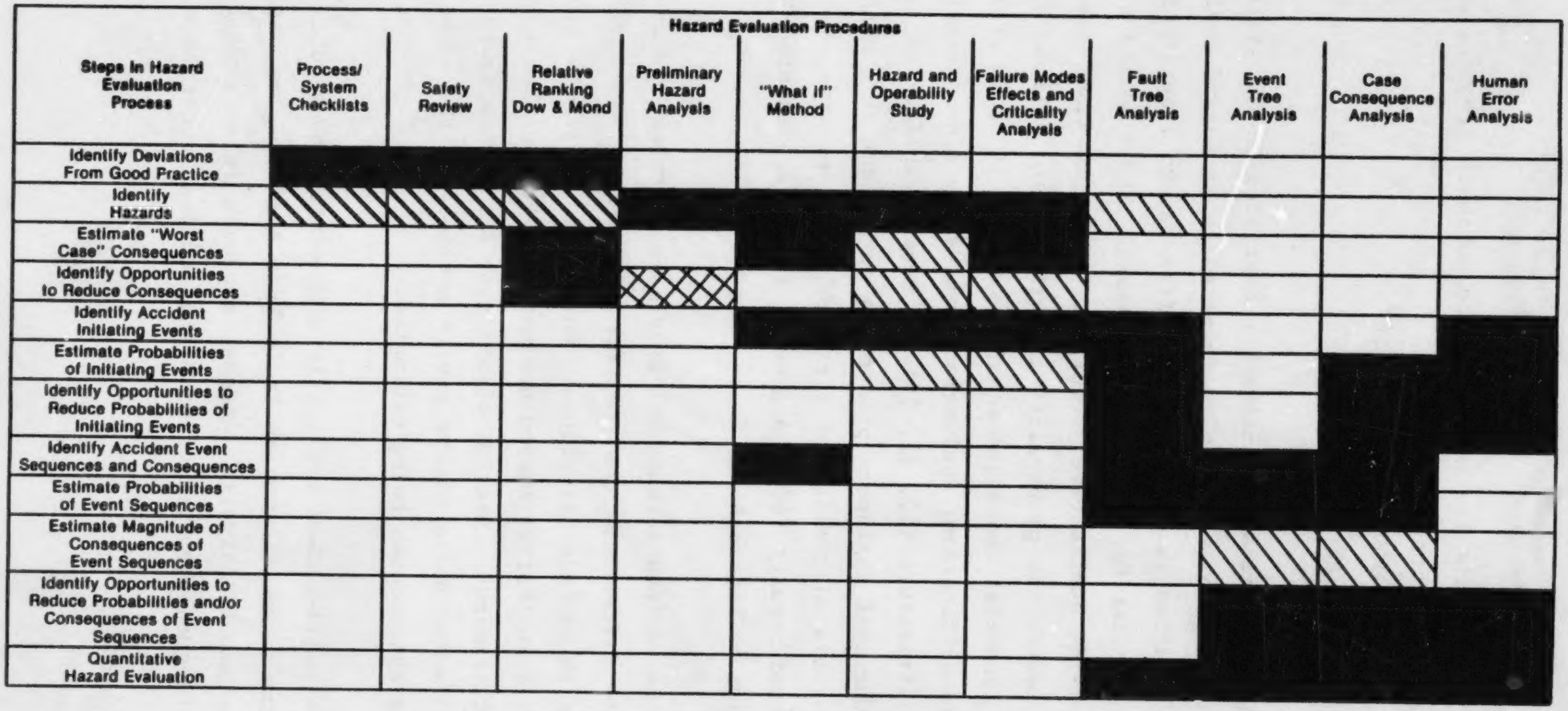
Like a FTA, the cause-consequence analysis leads to minimal cut sets which are all the combinations of basic events that can result in the various top events. Quantitative analysis can be applied to estimate frequencies or probabilities of various top events.

4.2 METHODS FOR HAZARD EVALUATION

Many of the methods for hazard identification discussed in the preceding section also apply to hazard evaluation (also referred to as hazard analysis or "HAZAN"). Hazard evaluation is the next step after hazard identification in the total assessment of risk for accidental releases. The evaluation step attempts to rank the hazards qualitatively, quantitatively, or both, seeks to identify measures that reduce the probability that the hazard will be realized, and examines the potential consequences of the hazard if it is realized. As with the method of identification, evaluation methods are also discussed in depth in the technical literature (12, 13, 15). A recent publication of the American Institute of Chemical Engineers presents a comprehensive summary of procedures with considerable discussion of distinguishing features, such as applicability and expected results (12). A summary table is presented, shown in slightly modified form in Figure 4-1.

It is clear that the various methods all have some features in common and yet are distinguished by differences that reflect the specific suitability of one method over another in certain situations. Only a few of the methods are specifically suited for quantitative hazard evaluations where probabilities of an accident are to be determined. Another significant difference is that some methods are hardware-oriented while others easily accommodate the effects of human interactions with the process being evaluated.

None of the listed methods deal explicitly with consequences outside the process itself, but some methods, such as Fault Tree Analysis, can easily accommodate such an extended analysis. Another approach is to conduct a completely separate consequence analysis, with the accident event being the starting point.



Steps In Hazard Evaluation Process	Hazard Evaluation Procedures: Process/ System Checklists	Safety Review	Relative Ranking Dow & Mond	Preliminary Hazard Analysis	"What If" Method	Hazard and Operability Study	Failure Modes Effects and Criticality Analysis	Fault Tree Analysis	Event Tree Analysis	Case Consequence Analysis	Human Error Analysis
Identify Deviations From Good Practice	■	■	■								
Identify Hazards	▧	▧	▧	■	■	■	■	▨			
Estimate "Worst Case" Consequences			■		■	▨	■				
Identify Opportunities to Reduce Consequences			■	▩		▨	▨				
Identify Accident Initiating Events					■	■	■	■			■
Estimate Probabilities of Initiating Events						▨	▨	■		■	■
Identify Opportunities to Reduce Probabilities of Initiating Events								■		■	■
Identify Accident Event Sequences and Consequences					■			■	■	■	
Estimate Probabilities of Event Sequences								■	■	■	
Estimate Magnitude of Consequences of Event Sequences									▨	▨	
Identify Opportunities to Reduce Probabilities and/or Consequences of Event Sequences									■	■	■
Quantitative Hazard Evaluation								■	■	■	■

Key:

■ Primary Purpose
▩ Secondary Purpose
▨ Provides Context Only
▧ Primary Purpose for Previously Recognized Hazards

6-86-24766a

Figure 4-2. Relationship between hazard evaluation procedures and hazard evaluation process.

Source: Adapted from Reference 12.

The consequence analysis can also be qualitative, quantitative or both. Numerous mathematical models have been proposed and some are in common use for predicting the effects of fire, explosion, and accidental releases. Methods for examining the effects of accidental releases are often based on various forms of dispersion models. A summary of procedures available up through the late 1970s is presented in Lees (1). The prediction of affected areas and of concentrations resulting from accidental releases can be combined with health and environmental effects data to estimate the severity of the consequences of any release in the affected area. A recent report reviews major available models (16).

A more detailed discussion of these methods is beyond the scope of the present work. The reader is referred to the general technical literature for more details.

SECTION 5

OVERVIEW OF THE PRINCIPLES OF CONTROL

Both regulators and companies need to be familiar with the fundamental principles of control: the regulator, to intelligently review and evaluate company control plans and practices; companies, to evaluate existing company practices and to implement safer practices.

This section of the manual presents an introductory discussion on control technologies as they relate to reducing the probability and consequences of an accidental chemical release. Three fundamental levels of control are addressed: prevention, protection, and mitigation. Specific process design considerations, physical plant design considerations, and procedures and practices are discussed as they relate to prevention. Various protection and mitigation technologies are also discussed. In addition, examples of possible causes of releases and potential controls are illustrated.

5.1 BACKGROUND

The control of accidental chemical releases involves reducing the probability and consequences of such releases. Such control can be viewed as consisting of three fundamental levels:

- Prevention,
- Protection, and
- Mitigation.

The purpose of prevention is to reduce the probability of accidental releases. Prevention refers to all those measures taken to ensure that the primary containment of the chemical, that is storage, transfer, and process equipment, is not breached. These measures include process design, physical plant design, and operational procedures and practices, and involve considerations ranging from process control and hardware design to operator training and management policy. The ideal result of a successful prevention effort is that accidental releases of a chemical from its primary containment do not occur. In reality, prevention can be successful in reducing the probability of a release to a reasonable minimum.

"Reasonable minimum" is an imprecise criterion; however, the inherent characteristics of any process are that equipment can fail, and people make mistakes, so that from time to time an accidental release event will happen. The probability can be reduced if appropriate prevention measures are taken. These prevention measures enhance the control of a process or the ability of the hardware to tolerate severe process conditions, process upsets, and human error.

When preventive measures fail, a second level of control deals with protection from releases. In the context of this manual, protection means to contain, capture, neutralize, or destroy a toxic chemical subsequent to release from primary containment, but before it escapes into the environment. Protective systems are defined as add-on equipment and processes systems not considered part of the actual chemical process system itself, but which control a potential release. Examples of protection technologies include diking, flares, and scrubbers. Protection systems will also fail from time to time.

A deficiency in a protection system when it is needed may allow a toxic vapor or gas to escape into the environment. Once this occurs, the consequences may be reduced by using effective mitigation measures. Mitigation refers to equipment and procedures that can reduce the concentration of a chemical below levels that would otherwise occur and hopefully below levels harmful to sensitive receptors. Measures include technical approaches such as water sprays, or steam curtains for dilution and dispersion, barriers for diversion and dispersion, and procedures such as closing doors and windows, and evacuation in affected areas. It should be noted that mitigation is not a back-up approach to protection as protection is to prevention. The latter two areas are directed toward stopping a release. Mitigation merely attempts to control a release that has already occurred.

A detailed discussion of prevention and protection is the subject of the manual on control technologies. Mitigation will be the subject of a separate manual. A summary of major considerations in these three areas is presented in the ensuing subsections.

5.2 PREVENTION

Prevention measures can be classified into the general topical areas of:

- Process design considerations,
- Physical plant design considerations, and
- Procedures and practices.

These measures include consideration of both operational and hardware aspects of a chemical process system. Operational aspects include both the inherent characteristics of the process itself and human aspects such as operator training, maintenance procedures, and general management policy and procedures. Prevention measures are applicable to new facilities as well as existing facilities, where they are the basis for process modification.

5.2.1 Process Design Considerations

Process considerations involve the areas listed in Section 3, which can be regrouped as follows:

- Chemical process characteristics;

- Control system characteristics;

- Hazard control for flow, pressure, temperature, quantity measurement, composition, mixing, and energy systems; and

- Hazard control for fire and explosion.

The design of a process in which toxic chemicals are used or produced should be based on sufficient data to ensure a safe operating system. Necessary data to be considered in the design process include, but are not limited to, the following: chemical, physical, thermodynamic, and toxicological properties of the individual chemical components used or produced in the process; the process potential for explosive reaction or detonation under normal or abnormal conditions; process reactivity with water or other common contaminants; possibility of self-polymerization or heating; potential side reactions and conditions under which they are favored; whether reactions are endothermic, exothermic, or thermodynamically balanced; the explosive range of volatile or gaseous components and the possibility of explosive mixtures during storage, processing, or handling; the possibility of dust or mist explosions; and interactions with materials of construction.

Flow, temperature, pressure, quantity measurement, and composition control are fundamental process variables. Mixing is a fundamental process phenomenon. These process elements have associated with them the basic potential operational hazards of any process. Prevention measures associated with these elements include the appropriate process control measures discussed above applied to the specific process effects and hazards of these elements. The fundamental hazards of all these variables arise from deviations that exceed the limits of the operational or physical system. For example, excess flow may be a hazard if it causes a change in a process system faster than the operator or control system can respond. The excess flow of a reactant in an exothermic reaction might cause a thermal runaway sooner than emergency cooling or other safety measures could be activated. Or, flow blockage could prevent cooling water flow in a critical circuit. For each of the above variables, there are specific measures that can reduce the chances for deviations or minimize their effects.

The control characteristics of the process should be understood and the control system should be appropriate for the system. This means that the process dynamics should be properly considered and the control system must be compatible with the available operating and maintenance staff knowledge and skills. Specific technological prevention measures in all control systems include using control components of greater reliability and accuracy and faster response times. A fundamental principle in control system components is redundancy, or the use of independent backup to critical components. The key word here is independent--to avoid a common mode failure in critical systems. For a specific process, reducing the probability or magnitude of process deviations or upsets that could lead to an accidental release may involve design changes in a control system ranging from individual components through the entire control strategy and hardware.

Fire and explosion protection is basic to release prevention. Preventing the conditions that lead to fire and explosion is inherent in the items already discussed above and also involves physical plant design considerations discussed in the next section. Once a fire has started in or near a process involving toxic chemicals, controlling the fire becomes of paramount concern. Design considerations for fire protection are based on the removal of fuel, oxygen, or heat from the fire. Adequacy and reliability of water supply, possible chemical fire fighting measures, and suitable fire fighting equipment are the primary process design considerations for fire protection beyond initial fire prevention through careful process design.

Explosion protection relies on preventing dangerous process conditions such as the formation of explosive mixtures from occurring, preventing contact of potentially explosive mixtures with ignition sources, and applying specialized explosion suppression systems. Explosion protection also relies on appropriate physical plant design considerations, as discussed in the next subsection.

5.2.2 Physical Plant Design Considerations

Physical plant design considerations address hazards and their control in the following areas:

- Siting and layout,
- Structures and foundations,
- Vessels,
- Piping and valves,
- Process machinery, and
- Instrumentation.

Hazards were discussed in Section 3. Control considerations are discussed here.

At a minimum, codes and standards should be followed in the design of each of these areas. However, additional protection measures above and beyond those specified by the codes and standards should be incorporated into the design based on the specific situation. Problems arise because codes and standards are not developed with specific situations in mind. Thus, code cannot be relied upon unless the basis matches the scenario of concern with great precision.

Siting is the first area considered. A plant's location might affect frequency or severity of an accidental release. Siting considerations include, but are not limited to, the following: drainage systems should prevent the runoff of spilled liquid chemicals onto adjacent properties and prevent the spread of toxic and/or flammable liquid chemicals in a manner that minimizes adverse effects within and outside of the plant boundaries; minimization of the effects of natural calamities such as freezing, fire, wind, floods, earthquakes, and landslides in contributing to an accidental release should be incorporated into equipment design, for example, different foundation designs in earthquake prone areas; the potential impact of accidents such as fires, explosions, or hazardous chemical releases at adjacent industrial facilities, roads, or railways should be recognized as a possibility; reliable water and power supplies should be available with backups where a failure could cause an accidental chemical release; and traffic flow patterns within the plant and around the perimeter should be designed to prevent congestion and allow access by emergency response vehicles and appropriate movement of personnel in an emergency.

The layout of a plant is the next area considered. Layout considerations include, but are not limited to, the following: process units and the equipment and piping within a unit should be arranged to minimize congestion; where possible, hazardous processes should be segregated from other hazardous processes or sensitive areas within the plant or plant property; adequate spacing should be available for access by maintenance and emergency response personnel and equipment; explosion barriers should be applied where appropriate as described, for example, in the Dow guide (17); escape routes for personnel should be easily accessible; and offices, lunchrooms, or other support structures should be located at the perimeter of the facility.

Foundations should ensure the stability of all vessels and non-transportable equipment containing hazardous chemicals. The design should be in accordance with recognized construction and material specification standards in the industry as a minimum requirement. The design should consider all normal and abnormal load and vibration conditions, as well as severe conditions caused by freezing, fire, wind, earthquakes, flood, or landslides. Transportable equipment should be secured to prevent the upset or accidental detachment of process lines conveying hazardous chemicals during use and should not be used to permanently replace a stationary piece of equipment unless a given situation dictates a preference or requirement for such transportable equipment from a safety standpoint.

Structural steel should, at a minimum, be designed and constructed in accordance with appropriate construction and material specification standards in the industry. The design should consider all normal and abnormal dead loads and dynamic loads resulting from wind, collision, earthquake, or other external forces. As a minimum, fireproofing should be used for areas in which hazardous chemicals are manufactured, stored, handled, or generated and such areas should conform with legally applicable codes and standards. Fire protection beyond minimum standards should be considered for hazardous areas in which hazardous chemicals are present.

Vessel design and construction should conform to recognized design and material standards for the specific application in the industry as a minimum. Standards and specifications should be reviewed for adequacy of criteria. Stricter standards may sometimes be appropriate. Design should consider the combination of conditions anticipated for quantity, fill rate, pressure, temperature, reactivity, toxicity, and corrosivity. As a minimum, all vessels should be equipped with the following safety features: overfill and overpressure protection and, where appropriate, vacuum protection; storage cooling systems for low boiling point liquids and liquefied gases; storage vessels should be surrounded by diking, firewalls, or other containment devices unless such features are deemed to create a more severe secondary hazard in specific cases; vessels and vessel fittings should be protected from damage caused by collision or vibration and should be adequately braced to support the weight of piping; columns should be adequately supported to withstand the maximum wind loads expected in the area; and operators should be trained concerning the vessel's limits for pressure, temperature, fill and emptying rates, and incompatible materials.

Additional items such as nitrogen blanketing, improved fire protection, or release reduction equipment (e.g., water or steam curtains) may be appropriate in certain situations.

All pressure vessels and vessel jackets should be fitted with adequate pressure and/or vacuum relief. The relief systems should be designed according to recognized design procedures and standards appropriate in the industry as a minimum. Stricter procedures and standards may sometimes be appropriate. Containment systems should be designed according to recognized design procedures for containment systems. Valves upstream of pressure or vacuum relief devices should be prevented from being closed in such a way that the vessel will be isolated from all pressure relief or vacuum relief. Where possible, a pressure trip system should be used along with a pressure relief system. This will help minimize the frequency of releases of hazardous chemicals through the pressure relief system. All pressure or vacuum relief devices should be inspected and maintained periodically as part of routine maintenance. Testing a values capacity should be done whenever any corrosion, fouling, or scaling has occurred. The adequacy of a pressure or vacuum relief system should be reevaluated when a vessel or process unit is used to handle more material, or a different material, than that for which it was originally designed.

As a minimum, heat exchangers should be constructed in accordance with accepted industry codes and standards. Standards should be reviewed for adequacy of criteria. Stricter standards may sometimes be appropriate. The materials of construction should be selected to minimize corrosion and fouling. All exchangers should be equipped with pressure relief, by-pass piping, and adequate drainage facilities. Exchanger design should allow for thermal expansion and construction without causing excessive stress on connections.

Turbines, drivers, and auxiliary machinery should be designed, constructed, and operated in accordance with applicable industry standards and codes. Standards should be reviewed for adequacy of criteria. Stricter controls may sometimes be appropriate. The equipment should have adequate protective devices to shut down the operation and/or inform the operator before danger occurs. Vibration sensors and/or shutdown interlocks may be required on high speed rotating equipment.

Heaters and furnaces should be located so as to minimize the possibility of bringing an open flame and/or extreme heat too close to a hazardous area. Basic units and controls should be designed in accordance with applicable standards and codes as a minimum. Standard should be reviewed for adequacy of criteria. Stricter standards may sometimes be appropriate. Examples of some of the basic requirements for furnaces include the following: provision for adequate draft; positive fuel ignition; automatic water level controls; pressure relief devices; and fuel controls. Air heaters should have igniters designed to provide positive ignition, proper safety controls on fuel sources, sight glasses for flame observation, monitoring devices for flame-out detection, and high temperature alarms. All heaters and furnaces should be inspected regularly. Where heaters and furnaces handle hazardous process materials, appropriate precautions should be taken to prevent releases in the event of tube failures, such as cracking, rupture, or plugging.

As a minimum, piping, valves, and fittings should be designed according to recognized industry codes and standards pertaining to working pressures, structural stresses, and corrosive materials to which they may be subjected. The thermal stress of repeated heating and cooling cycles or excessive temperatures, either high or low, should be considered. Some additional considerations include, but are not limited to, the following: dead ends or unnecessary and rarely used piping branches should be avoided; the type of pipe appropriate for pumping a hazardous chemical should be selected (e.g., using welded or flanged pipe instead of threaded pipe or using a suitable metal or lined metal piping instead of plastic wall piping); backflow protection should be installed where necessary, but backflow prevention should not be relied on as the only means of avoiding a backflow hazard; materials of construction suitable for the application should be selected and checked before installation to confirm the composition; recordkeeping on critical lines should be provided to prevent incorrect future substitutions; a means of remotely shutting off the flow in lines that carry a large volume of hazardous materials should be provided; adequate structural support should be provided to protect against vibration and other loads and to protect piping from potential collisions with vehicles in the vicinity; piping should be pitched to avoid unintentional trapping of liquids; and provisions should be made to ensure that a liquid-full condition cannot exist in a blocked section of line unless such a section of line has pressure relief.

Extra precautions should be taken in the design of pumps and compressors to minimize the potential for an accidental release of a hazardous chemical. Extra precautions include, but are not limited to, the following: where a pressurized hazardous material is being pumped or where the consequence of a seal failure could result in the accidental release of designated chemical, seals should be suitable to ensure reliable leak prevention (e.g., double mechanical seal with a pressurized barrier fluid that is compatible with the process fluid and equipment materials of construction); totally enclosed pump or compressor systems may be appropriate, if safely vented and inerted and monitored for oxygen where enclosure could result in a secondary hazard such as an explosive mixture; remotely operated emergency isolation valves and power shutoff switches may be appropriate on the suction and discharge sides of a pump or compressor; compressors or positive displacement pumps should be fitted with adequate overpressure protection; instrumentation to determine when flow into or out of a pump has ceased may be appropriate; where overheating could result in a fire or explosion, temperature monitoring may be appropriate; a backup power supply should be used for critical pumping systems; surge protection should be provided for pumps; and pumps, compressors, and their associated piping should have foundations and supports that protect against damage caused by vibration and any static and dynamic loads.

Every reasonable effort should be made to maximize the effectiveness of automatic process control systems for preventing an accidental release. All systems and instrumentation should be of the "fail-safe" type. Instruments should be made of materials capable of withstanding the corrosive or erosive conditions to which they are subjected. Central control rooms should be protected from fire and explosion hazards. An owner-operator should evaluate the ability of control systems to operate on manual control and should install a backup power supply in situations where operating on manual control would be impractical.

A variety of miscellaneous modifications may be appropriate, depending on the needs of the particular process unit. Examples of these modifications include, but are not limited to the following: the addition of control systems where none are presently employed; redundancy of key components; replacing components to improve accuracy, reliability, repeatability, or response time; the addition of a backup control system; simplification of an existing control system to improve operability; replacing a system that indirectly controls the variable of interest with a system that directly measures and controls the variable of interest; the addition of trip systems for emergency situations; and the redesign of a control system to conform to acceptable design standards.

All wiring and electrical equipment should be installed in accordance with the National Electric Code or stricter standards, if applicable. Electrical equipment for use in hazardous locations should comply with acceptability standards of recognized testing organizations. Standards should be reviewed for adequacy of criteria. Stricter standards may sometimes be appropriate. All electrical apparatus should be grounded.

Protection devices should have the capability of warning operating personnel when emissions are not being controlled. Plant alarms such as klaxons and sirens can be used to alert or signal such personnel. If a device is only used on an intermittent basis, then a testing program should be in place to ensure that the system will function when necessary. In addition, alarms should be tested, audited, and inspected to ensure reliability.

As a minimum, plant fire protection systems should be laid out in accordance with recognized codes and standards, such as those prepared by the National Fire Protection Association. A reliable water supply for all portions of the plant should be available. Flammable gas detection systems are recommended for locations where flammable chemicals are used at elevated temperatures and pressures. Central fire alarm systems should be in place. In addition to water, firefighting materials, such as spray foams, dry chemicals, and carbon dioxide, may be appropriate to handle various specialized types of fires.

5.2.3 Procedures and Practices

Operational Controls--

The following types of reactive materials should be stored so that the potential for mixing in the event of an accidental release is minimized by dikes or other physical barriers: materials that react to form a hazardous chemical; hazardous chemicals that react exothermically and thereby contribute to the rate of evaporation of the chemicals; and hazardous chemicals where reactions will contribute to the potential for an accidental release. Chemicals may be mutually reactive or reactive with other materials that may be nearby such as cooling or heating fluids, cleaning agents, and materials of construction.

Extra precautions may be required where there is a potential for mixing two incompatible chemicals within a process. Such precautions could include backflow protection, composition monitoring, and interlocks that prevent valves from being opened in combinations that allow for cross-contamination. Use of common lines for handling such incompatible chemicals should be avoided.

All materials of construction should be capable of withstanding normal operating conditions, normal shutdown conditions and potential deviations from normal operation. Where a specialized material is required, initial construction materials and replacement parts should be tested before use to ensure that the composition is consistent with specifications.

Safe procedures should be established to minimize the risk of an accidental release of a hazardous material during filling or emptying operations for tanks, vessels, tank trucks, or tank cars. Some considerations include, but are not limited to, the following: before material is added to a vessel, tank, tank truck, or tank car, the operator in charge of the addition should be able to verify what material is in the vessel or was last in the vessel; where hoses are used, a system should be in place to ensure that the proper type of hose is used for each application (e.g., different types of fittings for each application); hoses should be regularly inspected and maintained as necessary; efforts should be made to decrease the possibility of materials being sent to the wrong location; a system should be in place to prevent tank trucks or rail cars from moving away with a hose still connected; when a hose is used to transfer materials, it should be possible to stop the flow if the hose should fail; equipment should be grounded and operators trained in the appropriate methods for chemical transfer so as to avoid static charge accumulation.

Procedures and equipment should be in place so that every reasonable effort may be made to prevent an accidental release from the storage, handling, or treatment of wastes containing the hazardous chemicals.

Management Controls--

Programs to train plant personnel to handle normal operating conditions, upset conditions, emergency conditions, and accidental releases should be used. The programs should include written instruction, classroom-type instruction, and field drills. Periodic review and drill exercises should be part of such programs. Printed materials describing standard and emergency procedures should be provided to employees and revised as necessary to be consistent with accepted practices and recent plant modifications.

A plant-wide fire prevention and protection plan should be used. All operating personnel should be instructed concerning fire prevention and fire response. All facility personnel should be instructed in basic first aid and fire extinguisher use. The formation and training of specialized fire fighting teams and first aid teams should be in accordance with or exceed minimum specified requirements. All fire protection and prevention plans should be periodically reviewed and training drills held.

The owner/operator of a facility should formulate a comprehensive contingency plan to handle major plant disasters. All facility personnel should be trained to participate in plans for controlling facility emergencies related to accidental releases including emergencies such as large windstorms, earthquakes, floods, power failure, fires, explosions, and accidental releases of hazardous chemicals.

The contingency plan should describe coordination between the plant and local police, fire, and other emergency personnel. The plan should be specific in designating responsibilities and in addressing specific high-hazard situations that are possible for the plant. Communications responsibilities and procedures for relaying information during emergencies should also be clearly defined. The plan should include procedures for emergency notification of community and local governments. Where an accidental release could adversely affect the local community, the plan should include appropriate community emergency response procedures.

Simulated emergency exercises involving plant personnel should be performed on a regular basis. Disaster exercises that incorporate local emergency response organizations should also be undertaken periodically. Exercises may include tabletop exercises, emergency operations simulations, drills, and full field exercises.

An inspection, testing, and monitoring program for process equipment and instrumentation should be considered for areas of high hazard potential. Systems and components to which this program can be applied include, but are not limited to, the following: pressure vessels; relief devices and systems; critical process instruments; process safety interlocks (trips); isolation, dump, and drowning valves; process piping systems; electrical grounding and bonding systems; fire protection systems; and emergency alarm and communications systems. Engineering drawings and design specifications should be available for inspection, if requested.

Maintenance staff qualifications, skill level, and numbers should be consistent with the hazard potential at the specific operation.

A process safety review consistent with the magnitude of the modification should be made before implementing any modification. Documentation of modifications should be made and be available for inspection, if required.

5.3 PROTECTION

Protection measures are equipment and systems that prevent or reduce the quantity of chemical that is discharged in an incipient release that has already escaped primary containment. Protection technologies include flares, scrubbers, diking, and enclosures (i.e. containment buildings). Each of these technologies may be appropriate in specific circumstances, but none of them is universally applicable to accidental releases. Much depends on the specific toxic chemical involved, the quantity released, the rate of release, and how it is released.

Flares are commonly used in chemical process plants and in petroleum refineries to dispose of flammable gases and vapors resulting from normal operating upsets. They may be suitable in certain circumstances for the destruction of toxic chemicals that would otherwise be released to the environment. A prerequisite for destruction in a flare system is that the toxic material be flammable, or that it at least thermally decompose to less toxic compounds at flare flame temperatures. The other requirement is that the nature of the emergency discharge be compatible with the overall design and operating requirements of flares, such as the maintenance of specific gas velocities at the flare tip, and flow fluctuations within the design turn-down capabilities of the particular flare system. There may also be some real difficulty in the safe design of a flare system for the emergency discharge of toxic materials combined with normal process discharges of other process materials. Considerations in this area include the manifold system and how backflows and inappropriate mixing of incompatible materials might be avoided. A dedicated flare system is not necessarily a solution to the problem since keeping a flare on standby for a relatively rare emergency may not be feasible. Flares are an option that can be considered for the right circumstances for treating emergency discharges that are still confined by a pipeline or stack. The use of flares in such an application, however, must be carefully evaluated for possible secondary hazards that could make the use of flares more dangerous than not using them. For example, improper design could lead to flash back.

Scrubbers are another alternative for treating confined toxic discharges before they are released to the environment. Scrubbers have a long history of success in the process industries. Many of the considerations that apply to combined versus dedicated flare systems apply also to scrubbers. Scrubbers may be easier to maintain on a standby basis than flares, however.

The applicability of scrubbers depends on the solubility of a toxic chemical in a suitable scrubbing medium or the ability of the scrubbing medium to reactively neutralize the toxic chemical. Chemicals soluble in water or in various aqueous solutions are not a particular problem. Other toxic materials that require non-aqueous scrubbing liquids could present more difficulties. For example, it would be hazardous to use a flammable organic liquid as a scrubbing medium since one could easily create a flammable mixture. Most scrubbing systems that would be considered feasible for toxics would probably be based on aqueous scrubbing chemistry.

The type of scrubber that is suitable for use depends on the nature of both the discharge circumstances and the scrubbing chemistry. Since a low system pressure drop appears desirable for emergency scrubbing systems, simple spray towers may be appropriate in many applications. However, other types of scrubbers, such as packed beds and venturis, may also be appropriate in some situations.

Both scrubbers and flares can be used when the incipient release is still confined by piping or a stack, as might be the case with an emergency discharge from a relief valve. When the release results from equipment failure, such as a vessel or pipeline rupture, containment is required before the chemical can be disposed of by flaring, scrubbing, or in-place neutralization. Such temporary containment can be effected by diking and enclosures. Diking is a physical barrier around the perimeter of process equipment or areas designed to confine the spread of liquid spills and to minimize the liquid surface area. It can be simple earthen berms or it might be concrete walls. The diking might be little more than a high curb, or it could be a high wall rising to the top of a storage tank. The applicability of diking to spills of volatile liquids is readily apparent. By containing the liquid, the dike reduces the surface area available for evaporation, at the same time allowing a liquid to be cooled by evaporation so that the vapor release rate is diminished. In this way, diking can reduce the rate at which a toxic material is released to the air. The material can be allowed to evaporate at a manageable rate, collected into alternate containers, or neutralized in place.

Enclosures or containment buildings directly provide secondary containment for materials that have escaped primary containment. Such buildings can be designed to contain the toxic chemical until it is vented through an appropriate destruction system such as a flare or scrubber, collected into an alternative container, or neutralized in place. The primary difference between diking and a complete enclosure or containment building is the roof. The building confines virtually all of the material, whereas diking permits the continuous release of some of the material.

The applicability of either diking or enclosures must be carefully evaluated to determine if there might be secondary hazards associated with their use. For example, if the toxic material is also flammable, containment could create a fire or explosion hazard which could be as or more serious in its consequences than the original release itself. When properly applied, however, diking and enclosure can be effective protection technologies for accidental releases.

5.4 MITIGATION

Once a toxic chemical has been released to the air or that has the potential for entering the air, the primary concern becomes reducing the consequences to the plant and the surrounding community. Reducing these consequences is referred to as mitigation. Two aspects of mitigation are measures to control the quantity of toxic material that could reach receptors, and protect the receptors by ensuring that they remain in or are evacuated to locations that will prevent or minimize their exposure to the chemical. An emergency response plan addressing the issues is a key part of mitigation. The other part is the technology of controls. Mitigation technologies include such measures as physical barriers, water sprays, steam curtains, and foams. Mitigation technologies divert, limit, or disperse the toxic chemical that has been released to the atmosphere.

An emergency response plan must be based on identifying the consequences of the accidental release based on downwind quantities, concentrations, and duration of exposure at various receptor sites. The plan should include the information required to decide whether evacuation should be undertaken, or whether people in the path of the release might be better protected by remaining indoors in their own homes or other places. The plan should include specific first aid steps to be taken for the exposed population. Finally, the plan should lay out the specific responsibilities and activities of all facility personnel and community response teams in addressing the emergency.

Physical barriers may be specially constructed for the purpose, may be constructed for another purpose but function as barriers, or they may be natural terrain features. An example of a specially constructed structure is a diversion wall. A functional barrier could be a building. A natural terrain feature that might be a barrier is a hill or a line of trees. The primary function of a physical barrier is to protect especially sensitive receptors and provide additional time in which to respond to the accidental release emergency. A physical barrier located in the right place can also contribute to enhancing the dispersion of the released chemical. Physical barriers do not, however, directly capture or neutralize the chemical. They might improve the performance of other mitigation measures such as water sprays, however. Applicability and overall performance will depend on the nature of a specific release and on the meteorological conditions at the time of the release.

Water sprays and steam curtains are methods used to increase the dispersion rate of the released chemical, divert its direction, serve as a barrier between the toxic cloud or plume and potential receptors, and even absorb the chemical. The applicability and effectiveness of these methods depend on the nature of the release, the properties of the specific chemical, and the capability of extending to the highest effective point of a release. Effectiveness will also depend on meteorological conditions at the time these mitigation methods are applied.

A final mitigation technology is the use of foams. Foams are chemical mixtures that can be applied to liquid spills with special foam generating apparatus and, by covering the surface of the spill, reduce the rate of evaporation. Foams can be applied to spills that would otherwise result in the release of large quantities of toxic vapors as long as the foam is physically and chemically compatible with the spilled material. A fundamental requirement is that the foam have a density lighter than the liquid over which it is applied, and that the material over which the foam is applied does not easily diffuse through the foam. Foams may sometimes permit a spill to be transferred to containers for final disposition.

Mitigation technologies and community preparedness are the final line of defense in reducing the risks of accidental releases of toxic chemicals.

5.5 CONTROL TECHNOLOGY SUMMARY

The various technologies discussed in this section of the manual are discussed in greater detail in the manual on control technologies. It is apparent that controls applicable for the prevention of, protection from, and mitigation of accidental chemical releases, cover a wide range of both equipment and procedural measures. These measures may range from changes in the process employing a toxic chemical to the addition of specialized equipment outside of the immediate needs of the process itself.

Table 5-1 summarizes some locations and possible causes of accidental chemical releases, and presents corresponding control measures that might be applied. Selection of appropriate control measures depends on the results of a hazard evaluation that would define the most likely causes for a given process system. For most processes combinations of alternatives could reduce the probability of release and also reduce the consequences of any release that might occur. Additional discussion of this issue is also provided in the manual on control technologies.

TABLE 5-1. EXAMPLES OF POSSIBLE RELEASES AND CONTROLS

Location of Accidental Release	Cause	Potential Controls
External Causes		
General equipment failure	Fire at adjacent plant	Extra fire protection Protective barriers Coordination of emergency response efforts
	Explosion at adjacent plant	Protective barriers Coordination of emergency response efforts
	Traffic or rail accident from outside the plant	Protective barriers Reroute traffic flow
	Natural disaster, (flood, landslide, earthquake, windstorm)	Protective barriers Strengthened equipment foundations and structural support Alter surface contours to facilitate drainage around the plant Emergency response plans for each potential event
	Fire in adjacent process unit	Adequate spacing between process units Protective barriers Utility piping arranged in a way that prevents loss in adjacent units when one unit fails
	Explosion in adjacent process unit	Adequate spacing between process units Protective barriers Strengthened equipment foundations and structural support
	Loss of process control as a result of utility failure	Provide local or plant wide backup for crucial utilities Where possible, improve process operability so that the process can be manually operated or shut down when utilities are lost Arrange utility distribution so that utility losses will only effect a small area within the plant
	Trench fire	Install covers that are two thirds closed and one third grate Place flame traps periodically throughout the trenches
General process failure	Control room destroyed by fire/explosion	Protective barriers around control room Relocation of control room Where possible, improve process operability so that the process can be manually operated Pressurize control room with clean air supply Construct control room with extra fire protection
Pipebridge	Collision with plant vehicle	Protective barriers Warning signs of restricted clearance Rerouting in-plant traffic flow Remote shutoff valves on both sides of bridge

(Continued)

TABLE 5-1 (Continued)

Location of Accidental Release	Cause	Potential Controls
Vessel	Overpressure as a result of vessel BLEVE when exposed to fire	Adequate deluge system Water spray monitors available to cool the vessel Adequate pressure relief for handling heating from fire
Operating/Maintenance/Management Error		
General equipment failure	Thermal shock	Flow and temperature control Improve operator training Periodically inspect and test equipment for signs of fatigue
	Replacing a worn part with a part made of a material that is incompatible with the process	Establish testing procedures to certify materials of construction Where materials of construction are critical, have written details as to what materials of construction are appropriate or inappropriate for a given application
General process failure	Loss of process control as when a valve is incorrectly operated	Clearly label lines Physically segregate piping according to use Relieve congestion Eliminate unused and excess piping Improve employee training
Vessel	Tank overfill as a result of operator error	Level gauges and alarms Overflow catch tank Surround tanks with dikes Improve operator training
	Internal explosion as a result of static discharge in the presence of a flammable mixture	Operator training as to the hazards of static discharge Establish specific procedures for transfer operations
	Collapse due to underpressure when the tank is emptied or cooled too quickly	Operator training as to the physical limitations of the vessel and how this effects operating procedures Establish specific procedures for filling, emptying, heating and cooling
	Overpressure as a result of incorrectly adjusted relief valve	Test all relief valves after any adjustments have been made Allow only certified personnel to work on relief devices
Piping	Overpressure caused by reaction between process material and old material held up in a seldom used piping run	Train operators as to potential incompatibilities between process materials Blind off unused sections of pipe

(Continued)

TABLE 5-1 (Continued)

Location of Accidental Release	Cause	Potential Controls
Flange	Improper installation	Replace with a welded joint Maintenance training Establish a check procedure to certify work before operating Alternate variety of gasket
Pipe fitting	Poor weld	Radiographic weld test Personnel training
Threaded joint	Improper installation	Replace with a flanged or welded joint Weld seal threaded joints Leak or pressure test all critical joints Personnel training
Valve	Overpressure caused by water hammer	Operator training
Loading/Unloading operations	Mixing incompatible materials	Establish procedures for verifying heel composition Dedicate tanks for only one use
	Truck leaves without disconnecting hose	Block wheels during operation Install remotely operated emergency shutoff upstream of flexible line
Instrument Malfunction		
General equipment failure	Loss of reaction control as a result of inadequate control system performance	Install additional control systems where none are employed Redundancy of key components Upgrade components to improve accuracy, reliability, repeatibility or response time Backup the entire control system Simplify to improve operability Alter the variables that are monitored to more closely monitor the hazard Add trip systems Redesign the system to conform to present standards
	Loss of reaction control as a result of failure of an adequately designed control system	Install alarms For critical areas, install alarms that are audibly distinct Provide emegency backup systems such as emergency cooling Periodically inspect and test control systems Design so that the failure of one component will not result in a total control system failure Use only fail-safe equipment For critical areas, regularly replace portions of the system to prevent an on-line failure Use of non-interruptible power supply

(Continued)

TABLE 5-1 (Continued)

Location of Accidental Release	Cause	Potential Controls
Equipment Failure		
General equipment failure	Leak and ignition from hot oil system	Substitute with a nonflammable or less flammable material Locate furnace away from process
	Vibration	Additional supports Shortened piping (lower the vibration frequency) Pulsation dampeners Pipe loop to allow for expansion Determine if mechanical problem and repair it
	Loss of process control as a result of internal valve mechanism failure	A more reliable type of valve Periodically test valves
	Loss of process control as a result of check valve failure	Multiple check valves More sophisticated backflow protection Regularly inspect check valve internals
Vessel	Overpressure as a result of relief device failure	Size pressure relief devices using accepted practices Consider two-phase flow when sizing Install backup relief device Install a trip system as a first line of defense Design the vessel to fail in a manner that minimizes the release Enclose the vessel in a protective enclosure
Vessel shell	Corrosion	Fabricate the tank with an additional corrosion allowance Upgrade the materials of construction Use double walled construction Seal all insulation around fittings
Heat exchanger tube	Overpressure of trapped fluid	Shell and tube side pressure relief Periodic inspection of tube integrity
Drain line from storage tank	Valve failure	Add remotely operated emergency isolation valve Add a second drain valve in the line Limit the diameter of the drain line to 3/4 inch to restrict flow
Pipe break	Thermal expansion	Install a pipe loop to allow for expansion Use supports that allow for lateral movement
Bolted or riveted seams	Stress corrosion	Use welded seams

(Continued)

TABLE 5-1 (Continued)

Location of Accidental Release	Cause	Potential Controls
Welded seam	Poor fabrication	Radiographic weld testing Leak and/or pressure test equipment Use ASME code vessels
	Corrosion	Use ASME code vessels Use alternate type of weld Apply protective measures specific to the chemicals and type of corrosion involved
	Thermal shock Failure due to temperature or pressure cycles	Use ASME code vessels Set controls to restrict the rate and frequency of heating and cooling cycles Regularly replace crucial equipment before failure
Threaded joint	Corrosion	Replace with a flanged or welded joint Weld seal necessary threaded joints
Valve stem	Wear Overpressure	Tighten packing Choose a more reliable type of valve
Valve	Overpressure caused by water hammer	Limit the closing rate of the valve
Pump or compressor	Seal failure	Upgrade type of seal Install double mechanical seal with sealing fluid Enclose the pump or compressor in a ventillated enclosure Substitute with a sealless variety of pump
Design Error		
General equipment failure	Overpressure as a result of a valved off relief device	Interlock two parallel relief devices so that only one may be closed at a time
Vessel	Overpressure as a result of overfill	Restrict fillrate by limiting the size of fill lines Use identical capacity for fill lines and drain lines
	Loss of reaction control as a result of a loss of mixing	Monitor agitation directly by monitoring the mechanical drive assembly on the mixer or indirectly by monitoring temperature or flow
	Overpressure as a result of undersized relief device	Size using accepted methods Resize every time a system is used for a new service Consider the potential for two phase flow

(Continued)

TABLE 5-1 (Continued)

Location of Accidental Release	Cause	Potential Controls
Vessel (continued)	Internal tank explosion caused by a static discharge in the presence of a flammable mixture	Deflector plates at liquid entry Nitrogen blanketing Restricted feedrate Properly ground all equipment Use of explosion pressure relief
	Tank collapse as a result of emptying or cooling too quickly	Install breather vent or nitrogen blanketing Restrict the maximum possible empty or cooling rate
	Stress failure of a nozzle caused by inadequate pipe support	Added support for piping Additional reenforcement around the nozzle Wherever possible, place vessel fittings above the normal liquid level
Heat exchanger tube	Overpressure of trapped fluid	Provide shell and tube side pressure relief
Vent or vented enclosure system or vented enclosures	Internal explosion caused by ignition of a flammable mixture	Purge vents with inert gas Dilute with inert gas until the concentration is below the flammable limit Monitor for flammable mixtures
Piping	Incorrect materials of construction	Proper material specifications based on lab and pilot testing Inspect all parts to validate the material of construction and their integrity before installation during construction or maintenance
	Overpressure as a result of a reaction between process material and old material held up in a seldom used piping run	Simplify piping, eliminate dead ends or seldom used sections of pipe Install overpressure protection where mixing of incompatible materials is likely to occur
Pump or compressor	Blocked discharge, resulting in an overpressure	Provide upgraded overpressure protection Monitor flow
		Monitor temperature of the fluid in the pump case
Loading/Unloading operation	Truck overfill	Install remotely operated shutoff valves Install level monitoring controls

SECTION 6
GUIDE TO FACILITY INSPECTIONS

The preceding sections of this manual have broadly discussed the identification, evaluation, and control of hazards. In addition to procedures already discussed, there remains the actual inspection of physical facilities.

This section of the manual presents a brief example guide to facility inspections. General procedures including one possible approach to setting up and conducting an inspection is discussed. Specific procedures involving detailed inspection are also covered. Regulators may find this material useful as a guide to establishing their own procedures for facility inspections. Companies may find the information useful for the same purpose or for comparison with existing procedures. In either case, while the broad aspects of the procedures are applicable to most facilities that handle toxic chemicals, there may be variations in detail that are site-specific. These procedures are intended to initiate a thought process for an inspector knowledgeable about chemical processes.

6.1 BACKGROUND

Inspection of process facilities is an inherent part of reducing the probability of accidental chemical releases. Such inspections may be carried out by regulatory agencies or by companies themselves. The kind of inspection will usually differ for these two bodies; an inspection by a regulatory agency will generally be less detailed and focus on a few key items, whereas that by company will generally be more detailed and broader.

The hazard identification procedures discussed earlier can be used to identify key areas for inspection. An inspection should include all functional parts of a physical facility where a release could conceivably occur. These parts were generally identified in Figure 1-4, Section 1 of this manual.

The purpose of an inspection by a regulatory agency is to ensure that equipment and procedures for prevention and control of accidental releases are consistent with what a company has reported to the agency, and to determine if there may have been oversights in critical areas. The regulatory agency inspection will primarily identify problem areas. The purpose of an inspection by a company is similar, except that the time and resources available are likely to allow a more detailed look at the facility. The company's inspection will be much more focused on setting priorities for specific corrective actions rather than just identifying problem areas.

6.2 GENERAL PROCEDURE

There are many ways to set up an inspection evaluation protocol and conduct inspections. This section discusses one possible approach.

The overall procedure involves the following steps:

- Establishment of an inspection team;
- Determination of preliminary information requirements and acquisition of information including preparation of a facility questionnaire if necessary. The questionnaire will be completed by responsible parties at the facility to be inspected and returned to the inspection team if the team is from outside the facility;
- Review of the questionnaire and other preliminary information, including process flow diagrams, piping and instrumentation diagrams, operating manuals, and descriptions of maintenance

records to become familiar with the facility and identify critical areas for special attention;

- Meeting between the outside inspection team and a team of plant personnel including management to arrange a specific inspection plan, or planning meeting for the internal inspection team;

- A walk-through overview tour of the facility;

- In-depth inspections of specific areas according to the considerations discussed below in Subsection 6.2 and any other specific considerations that may be appropriate;

- A meeting between the outside inspection team and plant personnel at the conclusion of the inspection to review results, or a meeting of the internal inspection team for the same purpose;

- Preparation of a written inspection report which:

    -- states the purpose and summarizes the findings,

    -- identifies hazards found during the inspection,

    -- discusses the risk implications of those hazards, and

    -- discusses possible remedies to correct deficiencies and reduce hazards.

6.3 SPECIFIC PROCEDURES

Specific inspection procedures involve detailed examination of all parts of the process facility where toxic materials are used, manufactured, or stored. This inspection covers a number of specific elements which should include, but are not necessarily limited to:

- Process characteristics and process chemistry,
- Facility siting,
- Plant layout,
- Pressure relief systems,
- Maintenance and structural integrity,
- Fire protection,
- Electrical system,
- Transportation practices, and
- Contingency plan and emergency response coordination.

Details of specific considerations in each of these areas are presented in Appendix B of this manual. It must be emphasized that these are guidelines only, and are representative of, but not necessarily all inclusive of, the kinds of considerations and observations that should be made during inspections. The technical literature presents many other examples of how an inspection protocol would be set up.

SECTION 7

COSTS OF ACCIDENTAL RELEASE PREVENTION

With a commitment to and the knowledge required for accidental release prevention in place, the inevitable question is the cost of hazard identification and evaluation procedures, inspections, and control measures themselves. It is beyond the scope of this manual to exhaustively analyze the economic implications of accidental release prevention, but some general, very rough costs can be presented to provide a feel for the significance of economic issues.

This section provides cost data associated with the various hazard identification and evaluation procedures, inspections, and control technologies presented in previous sections of this manual. An example of the costs associated with the application of different combinations of controls to a specific system is illustrated. The implications of the costs of different control options is also discussed in light of policy planning.

7.1 COSTS OF HAZARD IDENTIFICATION, EVALUATION, AND INSPECTION

Attempting to assign specific costs to these activities is extremely difficult without specifics on the number, size, and type of facilities involved. As was shown in Table 4-1, formal hazard identification and evaluation procedures can be broadly classified in relative terms as low, medium, and high cost activities. Costs for any procedure depend on the complexity and size of the system being analyzed, and on the quality of the initial information on the system.

The literature from which the table was developed attempted to assign staffing and time requirements to each of the procedures listed. Careful analysis of these requirements suggests that some approximate costs can be developed as a lower bound for such activities. Results are shown in Table 7-1.

Costs for inspections are also highly variable, and again depend on system complexity, size, and quality of the initial information available. A minimal inspection might take at least four hours by one or two people, and a more detailed inspection might last two to three weeks with a team of three or four people. On this basis, estimated costs are as presented in Table 7-2.

These costs are intended as rough guidelines only, and can be expected to vary significantly in specific situations.

7.2 COSTS OF CONTROL TECHNOLOGIES

Costs of control technologies range from the costs of an individual component such as an additional thermocouple to costs of a complete alternatively designed process system for handling a toxic chemical. A fundamental concept in evaluating the costs of control technologies for accidental release prevention is that increased safety may result from increasing levels of controls. As controls are added to a system, costs will increase. It is possible to compare costs for systems with different levels of controls and evaluate the relative improvements in safety that might result. This could be done through estimates of the reduction in accident probability by quantitative fault or event tree analyses.

Costs of control technologies are addressed in more detail in a companion volume in this series on control technologies. The ensuing discussion presents an overview of control technology cost issues.

Table 7-3 summarizes cost ranges for some individual components that could be involved in enhancing the safety of a facility handling toxic chemicals, whether a storage or process facility. Costs for such enhancement could

TABLE 7-1. ESTIMATED LOWER BOUND COSTS FOR VARIOUS HAZARD IDENTIFICATION AND EVALUATION PROCEDURES[a]

Basis: One process unit[b] Procedure	Staffing (personnel)	Time[c] (days or weeks)	Cost[d] ($)
Checklist	1	1d-2w	1,040 - 10,400
Safety Review	3	3d-3w	4,680 - 23,400
Ranking Procedures	3	3d-1w	4,680 - 7,800
Preliminary Hazard Analysis	3	1d-1w	1,560 - 7,800
What-If Analysis	3	3d-1w	4,680 - 7,800
Hazard and Operability Study (HAZOP)	4	2w-6w	20,800 - 62,400
Failure Mode, Effects, and Criticality Analysis (FMECA)	2	2w - 6w	10,400 - 31,200
Fault Tree Analysis (FTA)	4	2w - 6w	20,800 - 62,400
Event Tree Analysis	4	2w - 6w	20,800 - 62,400
Cause Consequence Analysis	4	1w - 6w	10,400 - 62,400
Human Error Analysis	1	1w	2,600

[a] Based on staffing and time estimates in Reference 12.

[b] "One process unit" is roughly defined as a process system consisting of from one to perhaps three major unit operations (e.g., a complex chemical reactor system, or a simple reactor, a few heat exchangers, and a distillation column). The basis for the time and staffing for the various methods was not well defined in Reference 12.

[c] "d" = days; "w" = weeks

[d] Based on an average loaded rate of $65/hour per staff person.

TABLE 7-2. ESTIMATED COSTS FOR TYPICAL INSPECTIONS[a]

Team Size (Personnel)	Preparation	Time (Days) On-Site	Reporting	Cost ($)
3	0.5	0.5	1.0	3,120
3	2	5	2	14,040
3	5	15	10	46,800

[a] Preparation time, on-site, and reporting for team only based on loaded labor rate of $65/hour. Does not include plant personnel time required to assist inspection team. Does not include team travel costs or subsistence costs, if any, at site.

TABLE 7-3. COSTS OF SOME INDIVIDUAL INSTRUMENTATION AND CONTROL COMPONENTS FOR PROCESS SYSTEM SAFETY MODIFICATIONS[a]

	Capital Cost Range ($)	Annual Cost Range ($/yr)
Flowmeters	2,500 - 5,100	400 - 800
Flow indicators	400 - 1,000	60 - 150
Check valves	400 - 600	60 - 90
Pressure sensors	200 - 500	30 - 80
Pressure indicators	200 - 600	30 - 100
Rupture disks	150 - 300	30 - 50
Relief valves	7,000 - 12,000	600 - 1,000
Temperature sensors	200 - 300	30 - 50
Indicators	1,000 - 1,700	150 - 250
Auxiliary cooling water capacity	30 - 80 per gpm	5 - 12 per gpm
Auxiliary refrigerated brine capacity	3,000 - 8,000 per ton	450 - 1,200 per ton
Load cell systems	12,000 - 16,000	2,400 - 3,200
Level detection systems	1,100 - 15,000	80 - 2,300
Flow switches	ca. 500	ca. 80
Pressure switches	ca. 500	ca. 80
Density measurement	500 - 5,000	90 - 900
pH measurement	4,000 - 5,000	700 - 900
Viscosity measurement	2,000 - 12,000	350 - 2,200

(Continued)

TABLE 7-3 (Continued)

	Capital Cost Range ($)	Annual Cost Range ($/yr)
Chemical species analyzers[b]	700 - 40,000	130 - 7,300
Controllers	800 - 6,000	70 - 500
Control valves	3,000 - 6,000	500 - 900
Complete control loops	6,000 - 15,000	300 - 1,300

[a] Basis: All costs were based on specific standard sizes which are documented in a companion manual in this series on control technologies. Costs are intended as rough guides to general magnitude only.

[b] Specific types will be found in the manual on control technologies.

involve something as simple as adding a sensor where one was not previously used, or adding an extra one for backup, to something as complex as the design and implementation of an entirely different control system.

More extensive application of control technologies could involve numerous changes in individual components, and even complete add-on subsystems such as scrubbers. Table 7-4 presents an example of how different levels or combinations of controls might affect the costs of a toxic gas storage tank system, based on the conceptual drawing in Figure 7-1. This type of analysis can be applied to any system where the evaluation of the cost implications of accidental release control measures are desired.

All of these costs are to illustrate concepts and the general magnitude of costs. Actual costs will vary widely depending on the size and type of facility, exact specifications of equipment used, and the individual organization that builds or modifies the facility.

7.3 COST IMPLICATIONS FOR POLICY PLANNING

Costs of identification, evaluation, inspection, and control technologies can be used to roughly estimate costs of various programs for accidental release prevention and control by either regulatory agencies or companies. The costs given previously in Tables 7-1 and 7-2 can be used to estimate time requirements that might be associated with some of the regulatory aspects of hazard control plans evaluations by regulation, and compliance and preparation of plans by affected companies. Cost estimates such as shown in Table 7-4 provide a measure of what specific regulatory requirements involving process equipment would cost companies, excluding, of course, many indirect costs. This methodology can also be used to provide companies with a rough measure of cost impacts of various process control options.

A complete analysis of cost implications of accidental release control is beyond the scope of this manual, but the overview presented here should be useful for preliminary planning purposes.

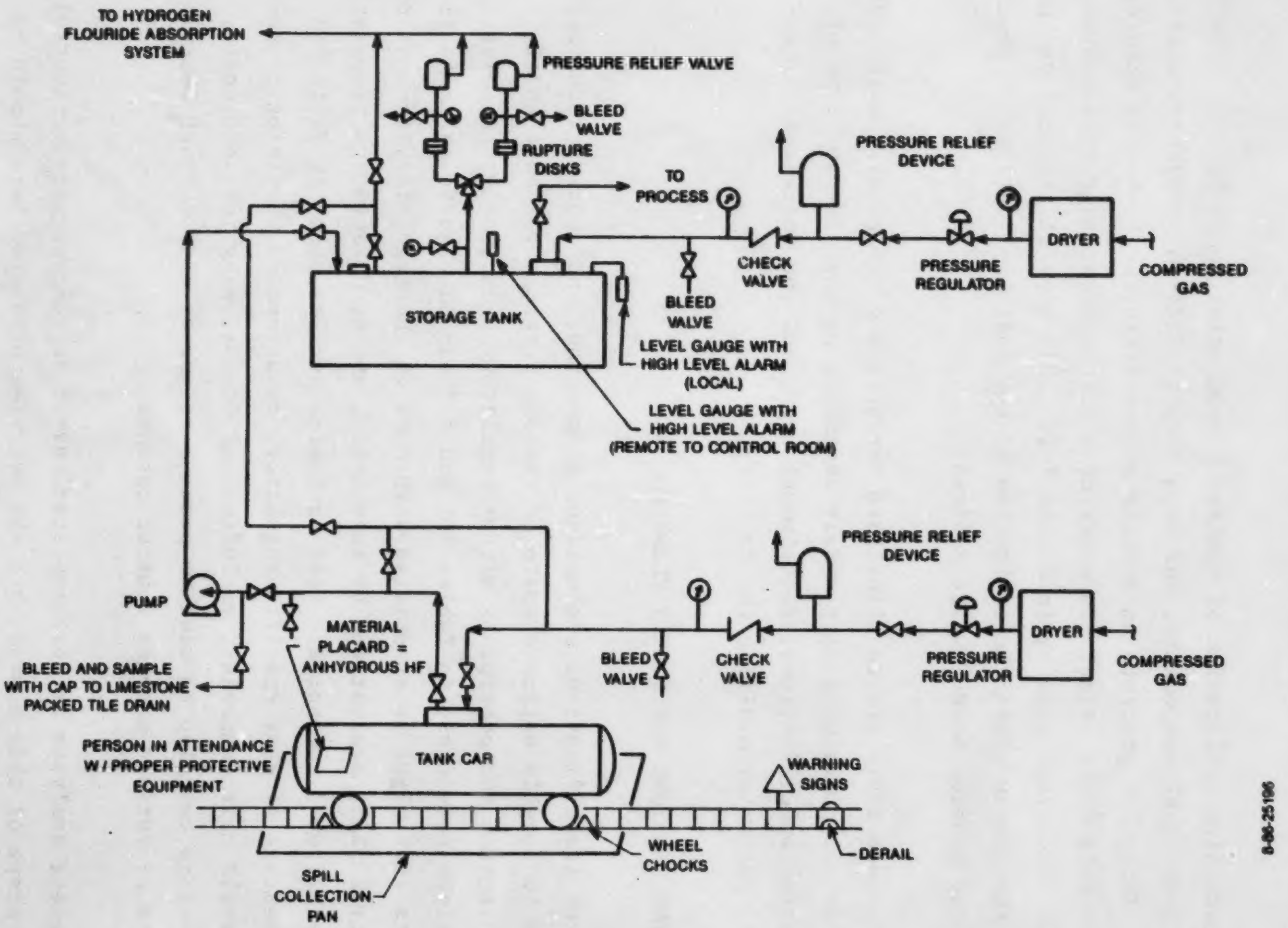

TO HYDROGEN FLOURIDE ABSORPTION SYSTEM
PRESSURE RELIEF VALVE
BLEED VALVE
RUPTURE DISKS
TO PROCESS
PRESSURE RELIEF DEVICE
CHECK VALVE
BLEED VALVE
PRESSURE REGULATOR
DRYER
COMPRESSED GAS
STORAGE TANK
LEVEL GAUGE WITH HIGH LEVEL ALARM (LOCAL)
LEVEL GAUGE WITH HIGH LEVEL ALARM (REMOTE TO CONTROL ROOM)
PUMP
MATERIAL PLACARD = ANHYDROUS HF
BLEED AND SAMPLE WITH CAP TO LIMESTONE PACKED TILE DRAIN
PRESSURE RELIEF DEVICE
BLEED VALVE
CHECK VALVE
PRESSURE REGULATOR
DRYER
COMPRESSED GAS
PERSON IN ATTENDANCE W / PROPER PROTECTIVE EQUIPMENT
TANK CAR
WARNING SIGNS
WHEEL CHOCKS
DERAIL
SPILL COLLECTION PAN
8-86-25196

Figure 7-1. Example of a toxic gas storage system.

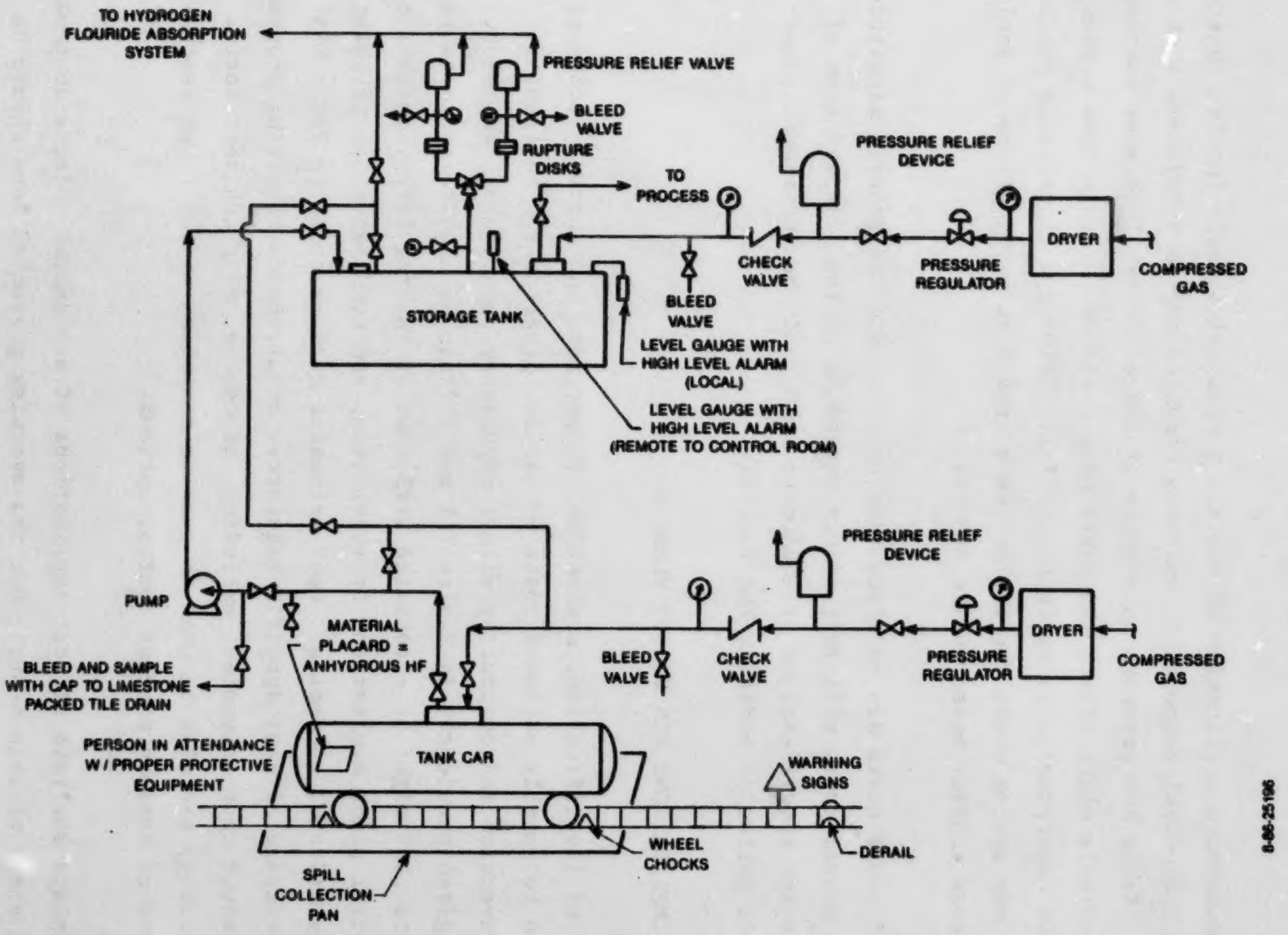

TO HYDROGEN FLOURIDE ABSORPTION SYSTEM
PRESSURE RELIEF VALVE
BLEED VALVE
RUPTURE DISKS
TO PROCESS
PRESSURE RELIEF DEVICE
CHECK VALVE
PRESSURE REGULATOR
DRYER
COMPRESSED GAS
STORAGE TANK
BLEED VALVE
LEVEL GAUGE WITH HIGH LEVEL ALARM (LOCAL)
LEVEL GAUGE WITH HIGH LEVEL ALARM (REMOTE TO CONTROL ROOM)
PRESSURE RELIEF DEVICE
PUMP
MATERIAL PLACARD = ANHYDROUS HF
BLEED VALVE
CHECK VALVE
PRESSURE REGULATOR
DRYER
COMPRESSED GAS
BLEED AND SAMPLE WITH CAP TO LIMESTONE PACKED TILE DRAIN
PERSON IN ATTENDANCE W / PROPER PROTECTIVE EQUIPMENT
TANK CAR
WARNING SIGNS
WHEEL CHOCKS
DERAIL
SPILL COLLECTION PAN
8-86-25196

Figure 7-1. Example of a toxic gas storage system.

TABLE 7-4. EXAMPLES OF CONTROL COSTS FOR A TOXIC STORAGE SYSTEM[a]

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Continuous moisture monitoring	7,500-10,000	900-1,300
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
Pressure relief		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Interlock system for flow shut-off	1,500-2,000	175-250
pH monitoring of cooling water	7,500-10,000	900-1,300
Alarm system	250-500	30-75
Level sensor		
- liquid level gauge	1,500-2,000	175-250
- load cell	10,000-15,000	1,300-1,900
Diking (based on a 10,000 gal. tank)		
- 3 ft. high	1,200-1,500	150-175
- top of tank height, 10 ft.	7,000-7,500	850-900
Increased corrosion inspection		200-400

[a] See Table 7-5 for design basis. Details of estimating procedures are provided in a companion manual on control technologies of this series.

TABLE 7-5. SPECIFICATIONS ASSOCIATED WITH TOXIC STORAGE SYSTEM

Item	Specification
Continuous moisture monitoring	Capacitance or infrared absorption system
Flow control loop	2-inch globe control valve, Monel® trim, flowmeter and PID controller
Temperature sensor	Thermocouple and associated thermowell
Pressure relief	
- relief valve	1-inch x 2-inch, Class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, carbon steel body, Monel® trim
- rupture disk	1-inch Monel® disk and carbon steel holder
Interlock system for flow shut-off	Solenoid valve, switch, and relay system
pH monitoring system	Electrode, electrode chamber, amplifier - transducer and indicator
Alarm system	Indicating and audible alarm
Level sensor	
- liquid level gauge	Differential pressure level gauge
- load cell	Electronic load cell
Diking	
- 3 ft. high	6-inch reinforced concrete walls, 5.2 yd^3
- 10 ft. high	10-inch reinforced concrete walls, 36.3 yd^3

SECTION 8
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APPENDIX A

This appendix contains a listing of acutely toxic chemicals which appeared in a U.S. EPA publication addressing community preparedness for chemical emergencies (19). There are actually two separate lists entitled Acutely Toxic Chemicals" and "Other chemicals." Some of the chemicals on the second list are also acutely toxic. Both lists appear separately in this appendix. At the time this manual was prepared word was received that three chemicals from the second list had been deleted. The modified list actually is the one used in this appendix.

11/01/85

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Acetone cyanohydrin	00075-86-5
Acetone thiosemicarbazide	01752-30-3
Acrolein	00107-02-8
Acrylyl chloride	00814-68-6
Aldicarb	00116-06-3
Aldrin	00309-00-2
Allyl alcohol	00107-18-6
Allylamine	00107-11-9
Aluminum phosphide	20859-73-8
Aminopterin	00054-62-6
Amiton	00078-53-5
Amiton oxalate	03734-97-2
Ammonium chloroplatinate	16919-58-7
Amphetamine	00300-62-9
Aniline, 2,4,6-trimethyl-	00088-05-1
Antimony pentafluoride	07783-70-2
Antimycin A	01397-94-0
Antu	00086-88-4
Arsenic pentoxide	01303-28-2
Arsenous oxide	01327-53-3
Arsenous trichloride	07784-34-1
Arsine	07784-42-1
Azinphos-ethyl	02642-71-9
Azinphos-methyl	00086-50-0
Bacitracin	01405-87-4
Benzal chloride	00098-87-3
Benzenamine, 3-(trifluoromethyl)-	00098-16-8
Benzene, 1-(chloromethyl)-4-nitro-	00100-14-1
Benzenearsonic acid	00098-05-5
Benzenesulfonyl chloride	00098-09-9
Benzotrichloride	00098-07-7
Benzyl chloride	00100-44-7
Benzyl cyanide	00140-29-4
Bicyclo[2.2.1]heptane-2-carbonitrile, 5-chloro...	15271-41-7
Bis(chloromethyl) ketone	00534-07-6
Bitoscanate	04044-65-9
Boron trichloride	10294-34-5
Boron trifluoride	07637-07-2
Boron trifluoride compound with methyl ether (1:1)	00353-42-4
Bromadiolone	28772-56-7
Butadiene	00106-99-0
Butyl isovalerate	00109-19-3
Butyl vinyl ether	00111-34-2
C.I. basic green 1	00633-03-4
Cadmium oxide	01306-19-0
Cadmium stearate	02223-93-0
Calcium arsenate	07778-44-1
Camphechlor	
Cantharidin	
Carbachol chloride	

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Carbamic acid, methyl-, O-[[(2,4-dimethyl...	26419-73-8
Carbofuran	01563-66-2
Carbophenothion	00786-19-6
Carvone	02244-16-8
Chlordane	00057-74-9
Chlorfenvinfos	00470-90-6
Chlorine	07782-50-5
Chlormephos	24934-91-6
Chlormequat chloride	00999-81-5
Chloroacetaldehyde	00107-20-0
Chloroacetic acid	00079-11-8
Chloroethanol	00107-07-3
Chloroethyl chloroformate	00627-11-2
Chloromethyl ether	00542-88-1
Chloromethyl methyl ether	00107-30-2
Chlorophacinone	03691-35-8
Chloroxuron	01982-47-4
Chlorthiophos	21923-23-9
Chromic chloride	10025-73-7
Cobalt	07440-48-4
Cobalt carbonyl	10210-68-1
Cobalt, [[2,2'-[1,2-ethanediylbis(nitrilomethy...	62207-76-5
Colchicine	00064-86-8
Coumafuryl	00117-52-2
Coumaphos	00056-72-4
Coumatetralyl	05836-29-3
Cresylic acid	00095-48-7
Crimidine	00535-89-7
Crotonaldehyde	00123-73-9
Crotonaldehyde	04170-30-3
Cyanogen bromide	00506-68-3
Cyanogen iodide	00506-78-5
Cyanophos	02636-26-2
Cyanuric fluoride	00675-14-9
Cycloheximide	00066-81-9
Cyclopentane	00287-92-3
Decaborane(14)	17702-41-9
Demeton	08065-48-3
Demeton-S-methyl	00919-86-8
Dialifos	10311-84-9
Diborane	19287-45-7
Dibutyl phthalate	00084-74-2
Dichlorobenzalkonium chloride	08023-53-8
Dichloroethyl ether	00111-44-4
Dichloromethylphenylsilane	00149-74-6
Dichlorvos	00062-73-7
Dicrotophos	00141-66-2
Diepoxybutane	01464-53-5
Diethyl chlorophosphate	00814-49-3
Diethyl-p-phenylenediamine	00093-05-0

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Diethylcarbamazine citrate	01642-54-2
Digitoxin	00071-63-6
Diglycidyl ether	02238-07-5
Digoxin	20830-75-5
Dimefox	00115-26-4
Dimethoate	00060-51-5
Dimethyl phosphorochloridothioate	02524-03-0
Dimethyl phthalate	00131-11-3
Dimethyl sulfate	00077-78-1
Dimethyl sulfide	00075-18-3
Dimethyl-p-phenylenediamine	00099-98-9
Dimethyldichlorosilane	00075-78-5
Dimethylhydrazine	00057-14-7
Dimetilan	00644-64-4
Dinitrocresol	00534-52-1
Dinoseb	00088-85-7
Dinoterb	01420-07-1
Dioctyl phthalate	00117-84-0
Dioxathion	00078-34-2
Dioxolane	00646-06-0
Diphacinone	00082-66-6
Diphosphoramide, octamethyl-	00152-16-9
Disulfoton	00298-04-4
Dithiazanine iodide	00514-73-8
Dithiobiuret	00541-53-7
EPN	02104-64-5
Emetine, dihydrochloride	00316-42-7
Endosulfan	00115-29-7
Endothion	02778-04-3
Endrin	00072-20-8
Ergocalciferol	00050-14-6
Ergotamine tartrate	00379-79-3
Ethanesulfonyl chloride, 2-chloro-	01622-32-8
Ethanol, 1,2-dichloro-, acetate	10140-87-1
Ethion	00563-12-2
Ethoprophos	13194-48-4
Ethyl thiocyanate	00542-90-5
Ethylbis(2-chloroethyl)amine	00538-07-8
Ethylene fluorohydrin	00371-62-0
Ethylenediamine	00107-15-3
Ethyleneimine	00151-56-4
Ethylmercuric phosphate	02235-25-8
Fenamiphos	22224-92-6
Fenitrothion	00122-14-5
Fensulfothion	00115-90-2
Fluenetil	04301-50-2
Fluorine	07782-41-4
Fluoroacetamide	00640-19-7
Fluoroacetic acid	00144-49-0
Fluoroacetyl chloride	00359-06-8

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Fluorouracil	00051-21-8
Fonofos	00944-22-9
Formaldehyde cyanohydrin	00107-16-4
Formetanate	23422-53-9
Formothion	02540-82-1
Formparanate	17702-57-7
Fosthietan	21548-32-3
Fuberidazole	03878-19-1
Furan	00110-00-9
Gallium trichloride	13450-90-3
Hexachlorocyclopentadiene	00077-47-4
Hexachloronaphthalene	01335-87-1
Hexamethylenediamine, N,N'-dibutyl-	04835-11-4
Hydrazine	00302-01-2
Hydrocyanic acid	00074-90-8
Hydrogen fluoride	07664-39-3
Hydrogen selenide	07783-07-5
Indomethacin	00053-86-1
Iridium tetrachloride	10025-97-5
Iron, pentacarbonyl-	13463-40-6
Isobenzan	00297-78-9
Isobutyronitrile	00078-82-0
Isocyanic acid, 3,4-dichlorophenyl ester	00102-36-3
Isodrin	00465-73-6
Isofluorphate	00055-91-4
Isophorone diisocyanate	04098-71-9
Isopropyl chloroformate	00108-23-6
Isopropyl formate	00625-55-8
Isopropylmethylpyrazolyl dimethylcarbamate	00119-38-0
Lactonitrile	00078-97-7
Leptophos	21609-90-5
Lewisite	00541-25-3
Lindane	00058-89-9
Lithium hydride	07580-67-8
Malononitrile	00109-77-3
Manganese, tricarbonyl methylcyclopentadienyl	12108-13-3
Mechlorethamine	00051-75-2
Mephosfolan	00950-10-7
Mercuric acetate	01600-27-7
Mercuric chloride	07487-94-7
Mercuric oxide	21908-53-2
Mesitylene	00108-67-8
Methacrolein diacetate	10476-95-6
Methacrylic anhydride	00760-93-0
Methacrylonitrile	00126-98-7
Methacryloyl chloride	00920-46-7
Methacryloyloxyethyl isocyanate	30674-80-7
Methamidophos	10265-92-6
Methanesulfonyl fluoride	00558-25-8
Methidathion	00950-37-8

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Methiocarb	02032-65-7
Methomyl	16752-77-5
Methoxyethylmercuric acetate	00151-38-2
Methyl 2-chloroacrylate	00080-63-7
Methyl chloroformate	00079-22-1
Methyl disulfide	00624-92-0
Methyl isocyanate	00624-83-9
Methyl isothiocyanate	00556-61-6
Methyl mercaptan	00074-93-1
Methyl phenkapton	03735-23-7
Methyl phosphonic dichloride	00676-97-1
Methyl thiocyanate	00556-64-9
Methyl vinyl ketone	00078-94-4
Methylhydrazine	00060-34-4
Methylmercuric dicyanamide	00502-39-6
Methyltrichlorosilane	00075-79-6
Metolcarb	01129-41-5
Mevinphos	07786-34-7
Mexacarbate	00315-18-4
Mitomycin C	00050-07-7
Monocrotophos	06923-22-4
Muscimol	02763-96-4
Mustard gas	00505-60-2
Nickel	07440-02-2
Nickel carbonyl	13463-39-3
Nicotine	00054-11-5
Nicotine sulfate	00065-30-5
Nitric acid	07697-37-2
Nitric oxide	10102-43-9
Nitrocyclohexane	01122-60-7
Nitrogen dioxide	10102-44-0
Nitrosodimethylamine	00062-75-9
Norbormide	00991-42-4
Organorhodium complex	PMN-82-147
Orotic acid	00065-86-1
Osmium tetroxide	20816-12-0
Ouabain	00630-60-4
Oxamyl	23135-22-0
Oxetane, 3,3-bis(chloromethyl)	00078-71-7
Oxydisulfoton	02497-07-6
Ozone	10028-15-6
Paraquat	01910-42-5
Paraquat methosulfate	02074-50-2
Parathion	00056-38-2
Parathion-methyl	00298-00-0
Paris green	12002-03-8
Pentaborane	19624-22-7
Pentachloroethane	00076-01-7
Pentachlorophenol	00087-86-5
Pentadecylamine	02570-26-5

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Peracetic acid	00079-21-0
Perchloromethylmercaptan	00594-42-3
Phenarsazine oxide	00058-36-6
Phenol	00108-95-2
Phenol, 2,2'-thiobis(4-chloro-6-methyl-	04418-66-0
Phenol, 2,2'-thiobis[4,6-dichloro-	00097-18-7
Phenol, 3-(1-methylethyl)-, methylcarbamate	00064-00-6
Phenyl dichloroarsine	00696-28-6
Phenylhydrazine hydrochloride	00059-88-1
Phenylmercury acetate	00062-38-4
Phenylsilatrane	02097-19-0
Phenylthiourea	00103-85-5
Phorate	00298-02-2
Phosacetim	04104-14-7
Phosfolan	00947-02-4
Phosmet	00732-11-6
Phosphamidon	13171-21-6
Phosphine	07803-51-2
Phosphonothioic acid, methyl-, O-(4-nitrophenyl...	02665-30-7
Phosphonothioic acid, methyl-, O-ethyl O-[4-...	02703-13-1
Phosphonothioic acid, methyl-, S-[2-[bis...	50782-69-9
Phosphoric acid, dimethyl 4-(methylthio)phenyl...	03254-63-5
Phosphorous trichloride	07719-12-2
Phosphorus	07723-14-0
Phosphorus oxychloride	10025-87-3
Phosphorus pentachloride	10026-13-8
Phosphorus pentoxide	01314-56-3
Phylloquinone	00084-80-0
Physostigmine	00057-47-6
Physostigmine, salicylate (1:1)	00057-64-7
Picrotoxin	00124-87-8
Piperidine	00110-89-4
Piprotal	05281-13-0
Pirimifos-ethyl	23505-41-1
Platinous chloride	10025-65-7
Platinum tetrachloride	13454-96-1
Potassium arsenite	10124-50-2
Potassium cyanide	00151-50-8
Potassium silver cyanide	00506-61-6
Promecarb	02631-37-0
Propargyl bromide	00106-96-7
Propiolactone, .beta.-	00057-57-8
Propionitrile	00107-12-0
Propionitrile, 3-chloro-	00542-76-7
Propyl chloroformate	00109-61-5
Propylene glycol, allyl ether	01331-17-5
Propyleneimine	00075-55-8
Prothoate	02275-18-5
Pseudocumene	00095-63-6
Pyrene	00129-00-0

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Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Pyridine, 2-methyl-5-vinyl-	00140-76-1
Pyridine, 4-amino-	00504-24-5
Pyridine, 4-nitro-, 1-oxide	01124-33-0
Pyriminil	53558-25-1
Rhodium trichloride	10049-07-7
Salcomine	14167-18-1
Sarin	00107-44-8
Selenium oxychloride	07791-23-3
Selenous acid	07783-00-8
Semicarbazide hydrochloride	00563-41-7
Silane, (4-aminobutyl)diethoxymethyl-	03037-72-7
Sodium anthraquinone-1-sulfonate	00128-56-3
Sodium arsenate	07631-89-2
Sodium arsenite	07784-46-5
Sodium azide (Na(N3))	26628-22-8
Sodium cacodylate	00124-65-2
Sodium cyanide (Na(CN))	00143-33-9
Sodium fluoroacetate	00062-74-8
Sodium pentachlorophenate	00131-52-2
Sodium selenate	13410-01-0
Sodium selenite	10102-18-8
Sodium tellurite	10102-20-2
Strychnine	00057-24-9
Strychnine, sulfate	00060-41-3
Sulfotep	03689-24-5
Sulfoxide, 3-chloropropyl octyl	03569-57-1
Sulfur tetrafluoride	07783-60-0
Sulfur trioxide	07446-11-9
Sulfuric acid	07664-93-9
TEPP	00107-49-3
Tabun	00077-81-6
Tellurium	13494-80-9
Tellurium hexafluoride	07783-80-4
Terbufos	13071-79-9
Tetraethyllead	00078-00-2
Tetraethyltin	00597-64-8
Tetranitromethane	00509-14-8
Thallic oxide	01314-32-5
Thallous carbonate	06533-73-9
Thallous chloride	07791-12-0
Thallous malonate	02757-18-8
Thallous sulfate	07446-18-6
Thallous sulfate	10031-59-1
Thiocarbazide	02231-57-4
Thiocyanic acid, (2-benzothiazolylthio)methyl...	21564-17-0
Thiofanox	39196-18-4
Thiometon	00640-15-3
Thionazin	00297-97-2
Thiophenol	00108-98-5
Thiosemicarbazide	00079-19-6

Acutely Toxic Chemicals
Alphabetic List of Common Names and CAS Numbers

Common Name	CAS Number
Thiourea, (2-chlorophenyl)-	05344-82-1
Thiourea, (2-methylphenyl)-	00614-78-8
Titanium tetrachloride	07550-45-0
Toluene 2,4-diisocyanate	00584-84-9
Toluene 2,6-diisocyanate	00091-08-7
Triamiphos	01031-47-6
Triazofos	24017-47-8
Trichloro(chloromethyl)silane	01558-25-4
Trichloro(dichlorophenyl)silane	27137-85-5
Trichloroacetyl chloride	00076-02-8
Trichloroethylsilane	00115-21-9
Trichloronate	00327-98-0
Trichlorophenylsilane	00098-13-5
Trichlorphon	00052-68-6
Triethoxysilane	00998-30-1
Trimethylchlorosilane	00075-77-4
Trimethylolpropane phosphite	00824-11-3
Trimethyltin chloride	01066-45-1
Triphenyltin chloride	00639-58-7
Tris(2-chloroethyl)amine	00555-77-1
Valinomycin	02001-95-8
Vanadium pentoxide	01314-62-1
Vinylnorbornene	03048-64-4
Warfarin	00081-81-2
Warfarin sodium	00129-06-6
Xylylene dichloride	28347-13-9
Zinc phosphide	01314-84-7
Zinc, dichloro[4,4-dimethyl-5-[[[(methylamino)...	58270-08-9
trans-1,4-Dichlorobutene	00110-57-6

OTHER CHEMICALS

Name	CAS Number
Acrylamide	79-06-1
Acrylonitrile	107-13-1
Adiponitrile	111-69-3
Ammonia	7664-41-7
Aniline	62-53-3
Bromine	7726-95-6
Carbon disulfide	75-15-0
Chloroform	67-66-3
Cyclohexylamine	108-91-8
Epichlorohydrin	106-89-8
Ethylene oxide	75-21-8
Formaldehyde	50-00-0
Hydrochloric acid	7647-01-0
Hydrogen peroxide	7722-84-1
Hydrogen sulfide	7783-06-4
Hydroquinone	123-31-9
Methyl bromide	74-83-9
Nitrobenzene	98-95-3
Phosgene	75-44-5
Propylene oxide	75-56-9
Sulfur dioxide	7446-09-5
Tetramethyl lead	75-74-1
Vinyl acetate monomer	108-05-4

APPENDIX B

EXAMPLE DETAILED PROCEDURES FOR HAZARD EVALUATION FACILITY INSPECTIONS

B.1 Process and Process Chemistry Evaluation

Purpose

The purpose of this evaluation is to identify the most critical areas in the process facility, based on the fundamental process chemistry and the sequence of unit processes and unit operations. Process chemistry considerations also include chemical reactions that might occur with materials that might unintentionally enter the process as contaminants.

Procedures

Procedures for this part of the evaluation include the following:

- Review of chemical equations for the process to identify fundamental hazard potential associated with basic process chemistry.
- Review of written process descriptions and process procedures to identify critical process areas or procedures.
- Review of process flow diagrams (PFD) and/or piping and instrumentation diagrams (PID) for the critical process areas identified above.
- Visual inspection of process areas, units, and specific critical equipment items for oversights or deficiencies using the information discussed in ensuing subsections as a guide.

- Comparison of process characteristics of the inspected process with other processes in the plant and the chemical industry as a whole to judge relative hazard potential.

- Application of various formal hazard identification and evaluation procedures to determine qualitatively how an accidental release might occur.

Key Factors

- Materials characteristics: evaluated to determine which materials in each process are potentially the most dangerous.

  -- Comparison of physical properties at both process and ambient conditions, including boiling point, melting point, vapor pressure, viscosity, and vapor density.

  -- Flammability as characterized by flashpoint, upper and lower explosive limits, and auto-ignition temperatures. Also, the chemical compatibility of mixtures in storage areas and during handling.

  -- Acute toxicity as characterized by the health effects of exposure by inhalation or skin contact.

  -- The evaluation of reactivity according to the following parameters:
    a. Whether reactions are exothermic, endothermic or thermodynamically balanced.
    b. Potential for uncontrolled reactions due to such things as decomposition, excessive temperature, backflow, or spontaneous polymerization.

c. Process reactivity with water or other possible contaminants.

d. Potential side reactions and conditions under which they are favored.

-- Corrosiveness considered in the context of the appropriateness of construction materials.

- Range of process conditions: the hazard potential is normally increased the larger the process and hence inventory of toxic material and the more severe the process conditions.

  -- Evaluation of process capacities in terms of operating throughput and in-process inventories of toxic materials.

  -- Classification of the reaction type based on a unit operation or unit process approach, for example, halogenation, polymerization, etc. Some types may show a history of more hazards than others.

  -- Categorization of reaction and separation process temperatures as low if less than 200°F, moderate between 200 and 500°F, or high temperature if above 500°F.

  -- Categorization of process pressures reaction and separation as low if less than 100 psig, moderate between 100 and 500 psig, or high pressure if above 500 psig.

  -- Evaluation of the process conditions relative to the physical properties of the chemicals.

- Mode of processing and process configuration: certain process types and configurations may be inherently more hazardous than others and hazards vary according to process characteristics (e.g., reaction time, volume, and type of reaction).

  - Evaluation of the implications of a process being batch, semi-batch, or continuous. For example a large inventory batch processes may be more of a hazard than a small inventory continuous processes.

  - Evaluation of process configuration in terms of operational sequences and physical placement of equipment.

  - Evaluation of process complexity in terms of the number of process steps and the nature of individual unit operations.

- Thermodynamics of Key Reactions

  - Exothermic reactions: considered more hazardous than endothermic or balanced reactions.

  - Qualitative evaluation of the hazard potential of an exothermic reaction according to whether it has a weak, moderate, or strong exotherm.

- Types of Instrumentation and Control Systems

  - Evaluation of the control system in terms of the reliability and responsiveness to deviations and corrective actions.

  - Consideration of relative reliability of pneumatic or electronic systems for given application.

  - Computer control systems: considered to be safer than reliance solely on manual controls, but computer systems should have some kind of manual backup.

  - Backup for increasing reliability: emergency cooling and heating systems, redundancy of the instruments, the instrument air supply, electrical power supply, and the computer system.

  - Evaluation of alarms and emergency shutdown systems for type, complexity, location and reliability.

- Process Isolation

  - Evaluation of the ability to isolate, quench, or dump the process materials in an emergency: location of shut-off valves and whether manual or automated shut-off is used.

  - Assessment of the possible effects of a fire, explosion, or release in a nearby process on the process being inspected.

- Operator Training

  - Evaluation of operator training for routine operations by review of operator training programs, operating manuals, and observations of and discussions with selected operators, and observations of operators carrying out their duties.

  - Evaluation of emergency awareness and preparedness for operator response to emergency situations including drills and tests in the same general manner as for routine operations.

B.2 Facility Siting Evaluation

Purpose

The purpose of this evaluation is to assess the potential impact of a facility's location on the frequency or severity of an accidental release and the vulnerability of the surrounding community to an accidental release.

Procedures

- Review of surrounding community: the evaluation of plant location relative to the surrounding community by direct observation and by maps and other written information.

- Review of climatic conditions: evaluation of the potential for severe climatic conditions and natural disasters from discussions with plant personnel, by direct observation and from government records for the area.

- Review of municipal utility reliability: evaluation of the reliability of municipal utilities (electricity, water, gas, etc.) from discussions with plant personnel, direct observations of main supply lines and information of past utility failures.

Key Factors

- Location in the community: evaluation of the plant location within the community in terms of proximity to other businesses and population centers, land use and terrain features in surrounding areas, wind patterns, and surface groundwater in the area.

-- Other businesses and population centers near the plant are potential receptors of any accidental releases, fires, or explosions in the subject facility. The potential danger varies with the specific hazard and magnitude of that hazard.

-- The exact extent of the hazard zone depends on the quantity released. In general, however, as a rough guideline, receptors within a few hundred yards of a facility may be considered sensitive receptors, while receptors beyond about 2-5 miles may be considered to be on the outer limits of typical hazard zones. It is emphasized here, however that toxic materials can be dangerous in clouds traveling many miles, and these distances are only for rough evaluation purposes.

-- An estimate of total population, including temporary population such as workers during certain parts of the day, within various distances of the plant (i.e., plant shutdown and construction personnel): the basis for estimating the number of people outside the plant who might be affected by a release.

-- Especially sensitive receptors such as schools, parks, and hospitals.

-- Land use in surrounding areas: noted in the context of the considerations just discussed, and especially prominent terrain features such as physical plants (i.e., columns and reactors), rivers, forests, and hills which could affect the dispersion of airborne chemical releases.

- Directions and speeds of seasonal and diurnal wind patterns for the facility. This is usually shown in a diagram called a windrose. Data for windroses are available for most major metropolitan areas and some other areas from the National Weather Service.

- The presence of surface and groundwaters in the area: noted in the context of the potential for contamination by sudden accidental releases of chemicals.

- Evaluation of the potential impact of an accidental release or other hazard coming from an adjacent business.

- Traffic flow patterns around the perimeter of the facility: especially points of congestion and the potential impact of traffic congestion on the movement of emergency response equipment and evacuated plant personnel.

- Climatic conditions

  - Evaluation of the potential for flood, landslide, brush fire, earthquake, severe wind or hail, subfreezing temperatures, or other climatic conditions including consideration of how such events might cause an accidental release.

  - Assessment of the need for other protective measures to reduce the potential for an accidental release resulting from climatic conditions.

- Review of municipal utility reliability
    - Review of past reliability of municipal utilities.
    - Consideration of unusual causes for utility failure, including downed power lines resulting from a vehicle collision with power line poles, or the loss of all utilities because of an earthquake.
    - Evaluation of backup utilities in the event of a facility-wide utility failure.

B.3 Facility Layout Evaluation

Purpose

The purpose of the plant layout evaluation is to determine if specific features of the layout could contribute to an accidental release. A primary consideration in the evaluation of the layout is the potential for an accidental release or other accident in one section of the facility to adversely affect other sections of the facility. As far as possible, each section within a facility should be protected from the effects of accidents in other sections of the facility.

Procedures

- Review of the total facility plot plan and plot plans of individual process areas.

- Tour of facility: to complement information obtained from plot plans.

- Discussions with plant personnel: information obtained directly from plant personnel, as required.

Key Factors

- Overall Plant Configuration

  - Review of the overall configuration of the facility, as well as individual process units.

  - Evaluation of the compatibility between materials in adjacent process units, especially considering how the possible release of a chemical, fire, or explosion in one unit could affect adjacent units and lead to additional accidental releases.

  - Evaluation of the compatibility of chemicals between process units and adjacent storage areas, and between the adjacent storage areas themselves

  - Evaluation of the location of individual facility process and storage areas relative to utility and other plant areas, considering such items as ignition sources, an incident in a process or storage area affecting a critical utility system, and potential effects on other areas from incidents in process and storage areas.

  - Evaluation of the distance between various parts of the facility and property lines and of special terrain features.

  - Process areas: should be well separated from utilities, storage, office, and laboratory areas.

  - Process and storage areas for flammable materials: should be in the prevailing downwind direction from ignition sources, or otherwise located away from ignition sources to the extent possible.

- Hazardous units: separation distances from all critical areas such as control rooms and process computer installations should at least be similar to those specified for flammable materials as given in Lees (1) for example.

- Administrative buildings and warehouses: preferably located at the periphery of the plant.

- Control rooms: should be protected from potential fire or explosion damage and from the adverse affects of an accidental release. Where possible, process control rooms should be located at the perimeter of the unit they control.

- Spacing of Process and Storage Areas

  - Inter- and intra-unit spacing: consideration of the distance between risk areas, and between equipment and systems within risk areas.

  - Spacing of equipment: should consider the nature of the materials, quantity, operating conditions, sensitivity of the equipment, the need to combat fires, and the concentration of personnel and hardware valuables in a given area.

  - Storage tanks: should be reasonably spaced and appropriately diked. Applicable codes and standards should be adhered to as a minimum requirement.

- Toxic materials in processes or storage areas: special considerations of spacing and isolation.

- Easy isolation and containment of hazardous materials in an emergency: for example, is a critical shutoff valve too close to the area of immediate impact in an accident?

- Vehicular Access and Clearances

  - Entrances and exits to various facility areas: should be adequate and free from uncontrollable obstruction in an emergency. For example, would a rail car accident on plant property block the only access road in or out so that emergency equipment could not respond to such an accident?

  - Access: there should be a minimum of at least two means of access or egress to the facility and critical areas within the facility.

  - Overhead clearances: observed for possible collapse and obstruction of access or egress in emergencies; also observed as the possible cause of a chemical release incident due to a collision with vehicular traffic.

- Security

  Security considerations are included in the facility layout evaluation because of the possibility of deliberate or accidental sabotage. The facility property should be fenced and access limited through gates under ready observation or direct control of facility security personnel.

B.4 Pressure Relief System Evaluation

Purpose

The purpose of this evaluation is to evaluate the adequacy of pressure relief systems designed to prevent rupture of vessels, pipelines, or equipment which would result in the uncontrolled release of toxic, explosive, or flammable materials.

Procedures

- Design and Procedures Review
  - Review of the need for and extent of pressure relief systems by examining process flow diagrams, process and storage conditions, and process instrumentation diagrams.
  - Review of maintenance and engineering records on relief systems.
  - Questioning of appropriate plant personnel about current installations, practices, and procedures.
- Field Inspection
  - Visual inspection of relief systems in a convenient priority sequence determined by a consideration of hazard potential, location in the plant, and inspection schedule.
  - Examination of process equipment for the presence of protection and its overall adequacy.

- Examination of individual relief devices and systems for proper configurations and specifications.

- Checking of nominal pressure and temperature ratings on vessels and other equipment against actual use conditions.

- Examination of the physical condition of pressure relief equipment.

Key Factors

- Evaluation of the appropriateness and applicability of the relief system includes the following considerations:

  - Relief systems: should be in place and functional on all equipment where it is required by codes and standards, and other equipment where the hazard for rupture from overpressure exists.

  - Safety relief valves: should be provided on the discharge side of positive displacement pumps, between positive displacement compressors and block valves, between back-pressure turbine exhaust flanges and block valves, and on any equipment where liquid can be blocked in and later warmed, or where chemical reactions, external fire, overfilling, or other process malfunction could result in equipment internal overpressure.

  - Vacuum relief devices: should be used where vacuum drawn on equipment, if blocked in, could cause equipment collapse from external pressure.

— Relief devices: should be of the proper type and specifications for the application. State-of-the-art equipment should be used where possible on equipment containing large inventories of toxic materials.

— Specifications: including sizes, construction materials, relief set pressure, set pressure tolerances, and service temperature range. These must be compatible with and specific to process conditions.

— Consideration should be given to the possibility of solids formation which could plug relief device inlets, outlets, and working mechanisms, (e.g. polymerization of monomer vapors from condensation on cold surfaces).

- Sizing

— Sizing: based on the maximum relief rate after consideration of four relief situations:

a. Fire exposure
b. Reaction/decomposition overpressure
c. Maximum fill rate
d. Thermal expansion

— Relief devices: should be sized using accepted procedures of the American Petroleum Institute (Recommended Practice for the Design and Installation of Pressure Relieving Systems in Refineries, Part I - Design, API, 1973) the National Fire Protection Association (NFPA 30 and NFPA 68), the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, consistent with type of service. Sizing for reaction/decomposition cases can be done using methods developed by the Design Institute for Emergency Relief Systems (DIERS), which was sponsored and published by the American Institute of Chemical Engineers (AIChE) (18).

- Configuration

  -- Evaluation of the possible hazards of manifolding, such as discharge of incompatible materials.

  -- Overall installation: should provide for ease of removal, inspection, testing, and replacement of the relief devices.

  -- Relief devices: should not be blocked by shut-off valves upstream or downstream unless a fail-safe system is provided with parallel relief such that both relief lines cannot be out of service at the same time, or some other means is used to protect the shut-off valves from improper closure. The former is sometimes accomplished using a 3-way, 2-port valve upstream of dual relief valves such that only one can be isolated at a time. Protection from shut-off is accomplished using breakable seals or even locks on shut-off handles to indicate or prevent unauthorized closure.

  -- Outlets not leading into common manifolds or flares: should be directed in a safe manner. This means that they should not be directed toward personnel or equipment where the discharge could cause fire, explosion, serious contamination, or other accidents. This is especially important in the ignited pressure relief of flammable materials where impingement of flame on vessels or other equipment could have serious consequences.

- Vents: should normally terminate outside of buildings and be at a height that minimizes exposure hazards.

- Discharge piping: should be supported independently of the relief valve to withstand dynamic forces involved when relief valve opens.

- Drain connections, weep holes, or rain guards: should be provided on relief discharge piping where rain, snow, or condensation could accumulate and plug the discharge. Low inertial covers may be provided in some cases.

- Rupture disks used in series with safety relief valves: a pressure gauge or other pressure indicator should be provided between the rupture disk and relief valve to indicate disk integrity. A pressure reading indicates that the rupture disk must be replaced.

- Blockage: auxiliary devices which might plug, such as check valves, or flame arresters should not be installed on relief system piping. Pipe plugs or caps should not be present on relief valves.

- Backpressure effects: should be considered for effect on relief valve operation, especially when several valves discharge into a common system.

- Location: Safety relief valves should be located as close as practical to the equipment they protect to minimize pressure drop and valve "chattering."

- Inlet piping: Should not be less than same nominal pipe size as relief valve inlet.

- Discharge piping: Should not be less than same nominal pipe size as relief valve outlet. Should be run as directly as possible with minimum changes of direction.

- Common headers: Should have a cross sectional area at least equal to the total of the connected valves.

- Pressure reducing stations: For steam, air gas, etc., should be fitted with safety relief valves on low pressure side. Safety relief valve should be sized to carry bull load of reducing valve and its bypass.

- Inspection and Testing

  - Safety relief valves: should be periodically inspected for structural integrity and for signs of corrosion or plugging. Materials that undergo polymerization, or are extremely corrosive may require especially frequent inspections.

  - Safety relief valve repair firms, including in-house testing units, should have a current certificate of authorization from the National Board of Boiler and Pressure Vessel Inspectors and have a "VP" stamp.

  - Pressure indicators on rupture disk installations: should be periodically checked for indications of rupture disk activation or leakage.

- Safety relief valves: should be tested for opening at the required set pressure and for proper reseating.

- Inspection frequencies: should follow a fixed schedule commensurate with the type of service and risk associated with a system failure. Safety relief valves should be inspected at least once in five years and as much as annually or more in high hazard applications.

- Records of inspections and testing: should be maintained.

B.5 Maintenance and Structural Integrity Evaluation

Purpose

The purpose of this evaluation is to assess the adequacy of maintenance procedures and the structural integrity of equipment.

Procedures

Discussions with maintenance personnel are held and written maintenance procedures and records are examined. The physical facility as a whole and individual equipment items believed to be most hazardous are examined during a site tour. Maintenance equipment and facilities are also observed.

Key Factors

- Maintenance Organization and Scheduling System: the overall maintenance organization and scheduling system is reviewed with key maintenance personnel by examining written procedures and records.

- Staffing levels should be appropriate for the size of the facility. Changes in staff levels are compared to changes in the physical facility. For example, has staffing kept pace with and is it of the appropriate type for recent plant modifications or additions?

- Examination of staff qualifications and skill levels relative to the hazard potential of the specific operation.

- Evaluation of the duties and responsibilities of contract versus in-house maintenance. In-house supervision or auditing of contract maintenance should be sufficient to ensure satisfactory contractor performance.

- Review of systems for work order initiation and implementation are reviewed.

- Review of procedures for maintenance scheduling and ranking to ensure that high hazard areas are properly recognized.

- Evaluation of the extent and adequacy of preventive maintenance. The frequency of such maintenance is considered in light of the kinds of equipment and systems involved, their potential inherent reliability, and the consequences of failure.

- Inspection, Testing, and Monitoring Program (ITM Program)

  - Determination of the presence or lack of an inspection testing and monitoring program for process equipment and instrumentation.

-- Evaluation of the ITM program in terms of four areas:
  a. Vessels, piping, and other process equipment,
  b. Rotating equipment, and
  c. Instrumentation.
  d. Utility systems (steam, water, air, electrical, etc.)

-- Factors considered for a formal ITM program:
  a. Severity of service (defined by operating temperatures and pressures and corrosiveness of materials used in the equipment),
  b. Hazard potential of specific chemical and equipment used, and
  c. Size of process facility and ITM program resource requirements.

-- Visual inspections of the presence and extent of corrosion, cracks, and improper installation such as inadequate foundations, missing supports, excessive vibration, etc.

-- Testing: may include determination of wall thickness, corrosion rates, the presence of cracks or pinholes, pressure tests, and temperature tests.

-- Testing methods: include ultrasonics, radiography, liquid penetrant, magnetic particle, eddy current, acoustic emission, visual leak testing, and others. Special tests may be required for vessels lined with glass, rubber, or other polymeric materials.

-- Assessment of the need for continuous monitoring methods or programs.

- Inspections for rotating equipment: include vibration analysis and monitoring, unusual sounds, and leakage around rotating parts, in addition to inspection items used for other equipment.

- Instrumentation ITM: depends on how important the instrumentation is to the process and the kinds of instruments involved. For example, thermocouples may be more reliable than resistance temperature devices.

- Maintenance Record Keeping

  - Engineering drawings and design specifications on equipment should be retained and readily available.

  - Records of inspections, tests, repairs, and modifications should also be available.

  - Equipment records should include a detailed safety check list for inspections, testing, and maintenance. Such check lists should cover special precautions and procedures to be taken before, during, and after maintenance work.

  - Maintenance work order and scheduling records should be maintained.

- Physical Condition of Equipment

  - Visual examination of the physical condition of equipment for signs of excessive corrosion, structural weathering, and physical flaws such as cracks or other physical damage.

- -- Examination of the integrity of insulation, especially of storage tanks and other equipment containing hazardous materials where accumulated moisture under damaged insulation could cause external corrosion.

- -- Examination of instrumentation and control equipment to ensure that housings and enclosures are in place to prevent dirt, moisture, and corrosion from impairing the accurate functioning of the equipment.

- -- Examination of control valves for worn or sticking stems, and of other valves for excessive corrosion, indicating they might be inoperable in an emergency.

- -- Examination of the integrity of foundations and structural steel supports for evidence of cracks, subsidence, and corrosion.

- -- Examination of rotating equipment for evidence of vibration, leaks, and unusual or abnormal noises.

- Design Specifications and Plant Practices

  - -- Design specifications for pressure and temperature: must be adequate for the intended service, and plant practices must be consistent with pressure and temperature specifications. Unfired pressure vessels as a minimum standard should be ASME Code, Section VIII Divisions 1 or 2 constructed and stamped. Other equipment should be designed and constructed in accordance with recognized codes and standards as a minimum requirement. Minimum standards may not be adequate for toxic materials.

-- Safety controls for overpressure and overtemperature: should be present and in good working order.

-- Type and location of sensors: as far as possible, a sensor should directly measure the variable that must be controlled.

-- Where backup systems are present: both the backup and the primary system should be in good working order.

-- The most effective backup system: one that functions on a different principle than the primary system.

-- Materials of construction and corrosion allowances: must be appropriate for the service at hand.

-- Proper construction and installation of equipment: including provision for ease of inspection and maintenance.

-- Piping systems: should be designed with allowance for stresses and movement due to thermal expansion, and systems should be properly supported and guided.

-- Piping systems: should be uncluttered, with valves and lines labelled or easily identifiable.

-- Systems: should be designed so that the failure of one valve or sensor does not result in an accidental release. All instrumentation should be fail-safe.

-- Valves and fittings: should be appropriate to their intended service. Threaded fittings are inappropriate for most piping handling hazardous materials.

-- Backflow protection: must be present in lines where backflow is a hazard. A single backflow device is rarely sufficient and some devices provide more reliable protection than others.

-- Flexible hoses: should be used only where necessary. Some type of operational audit system, or physical systems should be in place to prevent using hoses in situations they are not designed for. Hoses should be inspected regularly for signs of wear or abuse.

-- Freeze protection: should be provided where required, especially in cold water lines, instrument connections, and lines in dead-end service such as piping at standby pumps.

-- Lubrication and cooling systems for process machinery: should be in good working order. Oil filters should be used for lubrication to critical components.

B.6 Fire Protection Evaluation

Purpose

The purpose of the fire protection evaluation is to assess the potential contribution of fire or explosion to an accidental release. The fire protection system is evaluated for its ability to control or extinguish a fire, limit its extent, and limit the ensuing damage. The fire protection system must especially protect facilities containing toxic chemicals. A fundamental principle is to maintain operations outside the explosive range of flammable materials.

Procedures

- Review of Drawings
    - -- Examination of the plant process diagrams and layout drawings to identify areas where combustible, flammable, or explosive materials are used and stored.
    - -- Review of drawings of the fire protection systems to identify the location of the water supply, the distribution system, sprinkler systems, fire monitors, hydrants, and special fire fighting equipment.
- Review of Written Procedures
    - -- Review of emergency response plans to evaluate lines of authority, communications, and general procedures.
    - -- Documentation of fire protection team personnel assignments and training procedures.
- Discussions with Personnel: interviews with personnel responsible for fire protection concerning history, current procedures, problem areas, and future plans.
- Site Inspection: inspection of fire protection systems in light of the many considerations listed below under Key Factors.

- Comparison of specific practices with applicable fire codes, discussion of good practices that may not be explicitly covered by codes, and evaluation of practices in the context of site-specific considerations.

- Selected National Fire Protection Association Codes with special significance for chemical process plants include, but are not restricted to, the following (20):

Code	Title
11	Foam Extinguishing Systems
12	Carbon Dioxide Systems
12A & B	Halon Systems
13	Sprinkler Systems Installation
14	Standpipe and Hose Systems
15	Water Spray Fixed Systems
16	Foam-Water Sprinkler and Spray Systems
17	Dry Chemical Systems
19B	Respiratory Equipment for Firefighters
20	Centrifugal Fire Pumps
22	Water Tanks
24	Private Fire Service Mains
30	Flammable and Combustible Liquids Code
385	Tank Vehicles for Flammable and Combustible Liquids
386	Portable Shipping Tanks
43A	Storage of Liquid and Solid Oxidizing Materials
43C	Storage of Gaseous Oxidizing Agents
493	Intrinsically Safe Apparatus
496	Purged Enclosures for Electrical Equipment
50	Bulk Oxygen Systems
50A & B	Gaseous and Liquid Hydrogen Systems

Code	Title
54	National Fuel Gas Code
58	Liquified Petroleum Gases, Storage and Handling
59	Liquified Natural Gas, Storage and Handling
61A	Manufacturing and Handling Starch
63	Industrial Plants Dust Explosions
654	Plastics Industry Dust Hazards
66	Pneumatic Conveying Systems
69	Explosion Prevention Systems
71-72	(Signaling Systems and Fire Detectors)
76A	Essential Electrical Systems
231	General Storage Indoor
231C	Rack Storage of Materials
512	Truck Fire Protection
1961-1963	(Fire Hose and Connections)
1	Fire Prevention Code
13A	Sprinkler Systems Maintenance
27	Private Fire Brigades
291	Fire Hydrants Uniform Makings
329	Underground Leakage of Flammable and Combustible Liquids
497	Electrical Installations in Chemical Plants
68	Explosion Venting Guide
70B	Electrical Equipment Maintenance
80A	Protection from Exposure Fires

Key Factors

- Water Supply and Distribution

  -- Water sources: must be of adequate capacity, quality, and reliability. Supply pressure and a backup supply of adequate capacity are fundamental considerations.

  -- Redundancy of supply: may be advisable in some high risk situations. Water bodies may require pretreatment, such as filtration and chlorination to remove dirt and debris and control organisms that could plug the system. In-plant reservoirs or reserve supplies should typically provide at least 4 hours of coverage. This depends on the availability of other sources and the nature of potential fires.

  -- Distribution system: should consist of a looped or gridded network of large-diameter pipe, feeding all of the fire protection systems and equipment requiring water. Underground piping or appropriate freeze protection should be used, depending on climate. Where above ground portions of the system are run, they should be secure from mechanical, fire, and explosion damage, and freezing weather.

  -- Pumps: must provide adequate pressure and volume for the plant requirements.

  -- Additional pumps may be required because of plant expansion or modifications.

-- Pumps should be automatically started, but in either case startup must be reliable and secure in an emergency.

-- Adequate protection must be provided to ensure that lines, pumps, valves, and discharge devices do not freeze and impair the fire water supply.

-- Pump suction supply: normally sized to provide maximum flow rate for a minimum of four hours.

-- Evaluation of the sizing of the distribution system in light of the size of the facility and nature of the operation: normally a system is not sized to cover simultaneous fires in all areas. However, sizing of various portions of the system should account for the actual layout of a specific plant since in some facilities simultaneous demands on a fire protection system may be greater than at others. A minimum diameter for underground mains is 6 inches.

-- System pressures: sprinkler and water spray systems should normally require between 50 to 100 psig. Monitors, large hose systems and some foam systems may require 100 to 150 psig. Fire trucks supplied by a main can normally use 20 to 50 psig.

-- Fire pumps: should have capacities of 150% delivery requirement at 65% of rated head.

-- Fire pumps: should preferably have automatic start controls and a backup drive in the event of electrical power failure. Diesel drives are usually preferred, but if electric pumps are used, backups should be steam or diesel; again diesel is usually preferred. Electric pumps should be UL listed.

- Adequacy of coverage considers but is not limited to the following: fire protection for indoor and outdoor storage of flammable liquids in drums, adequate spacing and fire protection for flammable materials storage tanks, fire protection in warehouses, fire protection of cooling towers.

- Sectional control valves in the underground fire mains should divide the grid system into sections, limiting the area subject to a single impairment. The number of sprinkler risers and hydrants out of commission during any change or repair should be specified depending on the size of the area to be covered. With any one section shut off, at least one water supply should be available for the remainder of the system.

- The distribution system should ensure protection of structures and tankage.

- Sprinkler and Deluge Systems

  - Sprinkler and deluge systems: used for localized and broad area protection.

  - Automatic sprinkler protection: necessary for all buildings containing combustible construction, or flammable and combustible materials.

  - Evaluation of adequacy in terms of areas covered, the density of coverage (flowrate per unit area), the physical conditions of the system components, and frequency of testing.

- *Sprinkler* waterflow alarms: should give an audible local alarm and automatically transmit water flow signals to a central supervised location for any flow of water through the sprinkler piping.
- Automatic detectors: should be used where the quantity of combustibles is limited or sprinklers are not compatible with the hazard to be protected.

- Hydrants and Monitors
  - Hydrants provide hose connections to the fire protection water system. Monitors provide a fixed, quick response discharge point for fire protection water streams.
  - Sufficient hydrants having at least two 2.5 inch hose streams should be provided at any point in the property where fire may occur regardless of wind direction. This will require spacing hydrants 225 to 250 feet apart at plant with ordinary hazards. At plants having highly combustible occupancies, the spacing may need to be reduced to 100 to 150 feet. For facilities with non-combustible buildings and non-hazardous occupancies, hydrant spacing may be extended to 250 to 300 feet. For average conditions locate hydrants 50 feet from the building or equipment protected.
  - Fire protection monitors: should be used to protect equipment containing flammable liquids that is not in a building or structure protected by automatic sprinklers.

Their principle advantage is to provide a quick stream of water which can be operated by one man while hose lines are being laid. Spacings of 200 to 250 feet.

-- Assessment of the possibility of blockage of streams from fire monitors. Such blockage can occur when plant modifications are made. For example, an additional tank being put in behind an existing tank protected by a monitor. The new tank is blocked from the monitor stream by the existing tank. Portable monitors should be used in such cases.

- Building Protection and Portable Fire Extinguishers

  -- Evaluation of fire protection for buildings in terms of type of construction and contents.

  -- Small hose stations: located inside buildings so that every square foot of floor area is within 20 feet of a hose nozzle attached to not more than 75 feet of 1.5 inch woven jacketed rubber lined hose or equivalent. The nozzles should be the combination spray and solid stream with shutoff.

  -- Small hose: preferably attached to risers independent of the sprinkler system if hose streams are considered needed when sprinklers are not operating. If this cannot be arranged, small hose may be attached to 2.5 inch or larger pipe on a wet pipe system.

  -- Portable fire extinguishers: available in sufficient number, located where they are readily accessible, and in good operating condition.

- Fire walls, partitions, and barricades: provided to separate personnel areas, high value property, critical process units, and critical utility and auxiliary units.

- Foam Systems and Other Special Protection

  - Special fire hazard protection: includes foam systems, carbon dioxide, dry chemicals, and explosion suppression systems.

  - Fire extinguishing agents: compatible with process materials.

- Fire Proofing and Structural Protection

  - Fire proofing as a surface coating material: gunite or other synthetic material. A UL standard is for two hours of protection (21). However, hourly rating should be chosen as appropriate for situation.

  - Fire proofing: used on structural steel and on walls of vessels in a chemical process area, applied by spraying or spread coating onto the structure. It should be present in all areas where equipment may be exposed to fire. It should be used on all main load-bearing structural members that support either process piping or equipment within hazardous areas. Fireproofing on vessel walls is not a common practice.

  - Evaluation of the adequacy of fire protection in terms of type, thickness, coverage, and integrity of the coating. Gaps or peeling are a basis for rejection.

- Fireproofing should extend at least 30 feet above potential pool fires.
- Fire proofing should be provided for valve operators for all emergency safety devices.

- Mobile Fire Apparatus
  - Mobile fire apparatus: may consist of fire trucks or hand carts.
  - Fire apparatus: located in areas protected from but accessible to plant areas where fires are likely.
  - Equipment: should be in sound condition and subjected to periodic tests.
  - Evaluation of the adequacy of the equipment in terms of capacity and presence of the right kinds of equipment for the types of fires likely to occur in the specific facility. If ponded water is a source of supplementary water, an inlet system needs to be in place to ensure that blockage of suction hose can not occur.

- Alarm Systems
  - Alarm Systems: consist of various combinations of sensors and alarm devices and should be appropriate to the intended fire hazard. Sensors may be based on detection of flammable vapors or heat, for example. The selection would depend on the specific situation.

- Evaluation of sensor locations relative to locations of flammable materials and ignition sources.

- Evaluation of the physical condition of sensors and alarm systems.

- Evaluation of system adequacy in terms of location, coverage, and sensitivity.

- Flow alarms: should be provided on sprinkler systems to indicate their activation.

- Fire Emergency Response Organization

  - Lines of authority and communications for fire emergencies: should be clearly defined and readily available to all plant personnel.

  - Procedures, individual assignments, and emergency numbers: should be clearly posted in operator control room and other areas where personnel are likely to be in an emergency situation.

  - Training procedures: should be clearly defined and written. Training program should include both formal classroom type instruction as well as field drills with equipment. For high hazard areas good practice suggests simulated incidents as well. Training frequency should be consistent with the risk associated with a given process area.

  - A cadre of assigned individuals should form the core of a fire fighting team. The size of this team will depend on the size of the plant and the level of risk and must be adequate to at least contain an incident, if outside help is available. If outside help is not available the team must be of sufficient size and training to fully control an incident on its own.

- Maintenance of Fire Protection Equipment

  -- A regular program of scheduled inspections, tests, and preventive maintenance on fire protection equipment should be adhered to.

- Plant Layout Considerations

  1. Adequate spacing, diking, and drainage: should be provided for process equipment and tanks of flammable and combustible materials.

  2. Flammable storage pumps, compressors, and other equipment should be specific distances from ignition sources. Location near toxic materials should be avoided where possible.

  3. Adequate drainage: should be provided to avoid large concentrations of flammable materials in the event of spills. It should be pitched to drain away from high hazard structures with a minimum of 1% grade.

B.7 Electrical System Evaluation

Purpose

The purpose of the electrical system evaluation is to determine to what extent the electrical system could contribute to an accidental release through design, operation, or reliability deficiencies. All portions of the electrical system should be installed in accordance with the National Electric Code or stricter standards. Individual components should comply with the acceptability criteria of recognized testing organizations.

Procedures

The overall electrical system is reviewed through discussions with plant personnel, by a plant inspection tour, and by evaluation of written data and drawings.

Key Factors

- Reliability
  - -- Total power requirement and sources of electrical power to the plant: evaluation of the reliability of the sources (public utility system, private system, cogeneration system), including the history of outages, and examination of the physical source of power into the plant from outside power sources or from generating facilities within the plant for location and physical condition.
  - -- Evaluation of locational factors: proximity to flood-prone areas or areas within exposure zones of fire, explosions, or frequency of lightening.
  - -- Evaluation of the nature and extent of redundancy backup power system: focusing primarily on critical areas, including major power sources such as diesel generators for a whole process area, and battery backup units for individual processes or specific critical control elements.

-- Evaluation of historical reliability: including the frequency and duration of outages at the plant.

-- Determination of whether the facility has considered implications of power outages for the process unit as a whole as well as individual components such as instrumentation for specific intervals ranging from say, one minute to two hours.

-- Evaluation of voltage variations in light of possible effects on sensitive equipment. Could power surges damage a critical component in a control system such as software on a disk drive in a process control computer?

-- Evaluation of the configuration of the distribution system in terms of the adequacy of loops or independent circuit to different process area. Within a process area, electrical load blocks should correspond to process load blocks.

-- Electrical system: should be physically protected to minimize exposure to fire, corrosion, and mechanical damage; should be simple in schematic and physical layout to minimize human error in isolation load transfer; and should be accessible for ease of repair and maintenance.

-- Electrical system: should have adequate instrumentation for monitoring and the efficient diagnoses of failures, and protection by fuses and circuit breakers should be adequate.

-- Bonding and grounding: should be provided to protect personnel and protect systems from static buildup and lightening.

-- Maintenance and testing: the nature, frequency, and adequacy for power transformers, circuit breakers, relays and other devices, whether by the utility company, outside contractors, or the company, is evaluated.

- National Electric Code (NEC) Compliance

  -- The electrical system in a chemical plant must conform to the specifications for hazardous locations as specified in Section 501-5(a) of the National Electric Code (NEC).

  -- Process and storage areas are viewed in terms of the NEC hazardous location class, division, and grouping system. For example, Class I - Division II - Group D describes areas where flammable liquids and gases are handled, but are normally confined within closed systems, and where chemicals are typical organics. Other common categories for chemical plants include chemicals in Groups B and C. Class II areas, which is for atmospheres containing combustible dust, and Class I - Division I service, which is for atmospheres which continuously or intermittently contain high concentrations of flammable gases or vapors.

  -- Key principles to be checked: isolation of the electrical system components and containment of the flame front should ignition occur inside of equipment. In practice this is accomplished by sealed conduits, circuit breakers, lights, motors, and switches.

- Evaluation of proper pressurization and venting of closed areas.

- Inspectors: should be alert to the use of any portable electrical equipment not conforming to NEC codes.

- Evaluation of equipment maintenance conditions by observations of specific components of the electrical system such as: outside electric lines, insulators, support structures, switchgear, distribution panels, circuit breakers, lighting, grounding systems, motor starters and control centers, generators, transformers, relays, and lightening arresters.

B.8 Transportation Practices Evaluation

Purpose

The purpose of this evaluation is to assess the potential for a transportation incident causing an accidental release on plant property or elsewhere. Areas of concern include: loading and unloading procedures, adequate design of vehicles to handle the materials they transport, inspection and maintenance practices, and practices regulating the movement of vehicles within the plant.

Procedures

- Review of written guidelines and procedures pertinent to in-plant transportation practices.

- Inspection of loading and unloading areas, along with equipment and selected vehicles that happen to be present at the time of the visit.

- -- Discussions with both supervisory and operating personnel associated with transportation.

Key Factors

- Review of General Transportation Procedures.

  - -- Determination of vehicle type and of the rationale for the use of these vehicles. The compatibility of the vehicle with the type of service is evaluated in terms of materials being hauled in adherence to Department of Transportation requirements as well as special procedures and requirements established by the individual plant and company.

  - -- Evaluation of construction materials, and vehicle tank specifications in terms of pressure ratings, temperature ratings, wall thicknesses, valving, and on-vehicle sensors and instrumentation relative to the kinds of materials being shipped.

  - -- Evaluation of special practices, such as refrigerated and insulated vehicles for temperature sensitive products from a "what-if" mentality.

  - -- Brief visual inspections of vehicles may be made at the time of the inspection to look for malfunctioning, poorly maintained, or incorrect equipment, such as inappropriate pressure relief devices.

  - -- Review of plant procedures for routine inspections.

- Consideration of extra precautions taken for pressurized tank vehicles and high hazard materials.

- Review of certification procedures, usually through discussions with plant personnel. Such procedures would cover verification of the previous contents of the vehicle, cleaning after the last load, and similar considerations.

- Review of numbers, frequency of shipments, and sizes of shipments.

- Review of Loading and Unloading Operations

  - Examination of the use and scope of loading checklists.

  - Methods of overfill protection: common procedures for overfill protection include level sensors, automatic shut-off actuated by quantity totalizers, scales and load sensors, and reliance on operators. For hazardous materials an overfill protection system should have a back up.

  - Spill control measures: provisions should be available for both containment and cleanup, and where highly volatile materials or gases are involved, the plant should have a contingency plan for responding to air borne releases.

  - Availability of automatic shut-offs actuated by abnormal conditions and remote shut-offs: in case equipment can not be reached during an emergency.

- The responsibilities of the plant personnel and the driver: should be clearly defined and understood. For high hazard loading and unloading operations a plant representative should always be present.

- Review of labeling, stenciling, placarding, and other informational practices for compliance with DOT requirements and a plant's own special requirements.

- Review of controls on in-plant routing and stationing of vehicles. Potential hazards related to these factors include the potential for vehicular collisions with equipment in tight areas and vehicle accidents caused by poor locational practices. As an example of the latter, a fully loaded tank trailer parked off the pavement on soft ground, could overturn as a result of the wheels sinking on one side and the vehicle falling over.

- Definition of procedures for the management of rail car traffic on the plant premises. Special provisions for protection against derailment incidents are noted.

- Review of procedures for dealing with liquid heels in tank vehicles. It is common practice not to sample or analyze the heels in vehicle tanks dedicated to a single service. Plant procedures for avoiding cross-contamination of products in transportation vehicles and receiving racks are evaluated.

- Evaluation of equipment condition and its use. For example, do hoses show signs of significant abrasion and where? Are couplings appropriate for the type of service? What precautions are taken to maintain cleanliness in filling and unloading equipment where contamination could be hazardous? Is equipment being used as it was intended, or has jerry-rigging occurred as products have changed?

- -- Evaluation of precautions used for static electricity grounding.
- -- Check valves and/or other precautions: should be in place to prevent backflow and siphoning conditions form occurring.
- -- Color coding or other means of designating multiple lines and spouts: desirable at multi-material loading and unloading facilities.
- -- Are flow rate limiters in use?
- -- Is there thermal expansion relief for blocked-in valve lines?
- -- Evaluation of procedures to prevent drive-away with the attendant breakage of lines and accompanying chemical releases.
- -- Recalibration of gaging and metering equipment: should be carried out periodically.

- Off-Site Risks
  - -- Review of driver qualification, training, and certification procedures.

-- Review of accident histories for clues as to potential causes and impacts of future incidents. Changes in equipment or procedures occasioned by previous incidents are noted.

-- Review of routing procedures in the context of DOT regulations, special local rules, and other considerations that may be specific to the plant and the materials it handles.

  a. DOT regulations
  b. Other considerations

B.9 Contingency Plan and Emergency Response Coordination

Purpose

The purpose of the emergency response evaluation is to ensure that adequate procedures and equipment are in place to reduce the effects of an accident on people and property both within and outside the plant. Plant personnel and, where necessary, personnel from local emergency response agencies should be trained to participate in plans for controlling plant emergencies during large windstorms, earthquakes, floods, power failure, fires, explosions, and accidental releases.

Procedures

- Review of Written Procedures: written procedures are reviewed and the accessibility of these procedures to plant personnel are observed. Written procedures are evaluated in terms of comprehensiveness and specificity to the peculiarities of the individual facility. Recognition of the most significant hazards is noted.

- Discussions with Plant Personnel: the interviewing of selected plant personnel to evaluate their perceptions, to gauge their knowledge and attitudes toward emergency response, and to obtain additional factual information for use in the evaluation.

Key Factors

- Evaluation of contingency plans for dealing with various emergencies in terms of the following:

  -- The plan should be comprehensive and cover fire, explosion, and chemical releases.

  -- The plan should be specific. It should clearly designate responsibilities for individual unit personnel as well as plant personnel involved in fire fighting teams, medical teams, evacuation teams, etc. It should also address specific high hazard situations such as incidents in specific units or process areas, and specific kinds of incidents such as the accidental large release of a toxic chemical.

  -- Plans should be up to date. A process plant is rarely a static entity. Changes and modifications made over the years may affect process hazard potential. Corresponding changes in emergency response plans should also be made and clearly dated to allow evaluation of the appropriateness of the current plan.

  -- Evaluation of the availability of the plan to plant personnel: this includes physical distribution of the plan and the way it is stored and treated by plant personnel.

  - -- Responsibilities for personnel: should be clearly defined. The definition of responsibilities for the evening and night-time work shifts is especially important, since staffing on these shifts is usually less than in the day time.

- Personnel Training

  - -- Personnel training programs: should include written materials and include both formal "class room" instruction as well as field drills.

  - -- Instruction and drills: commonly cover routine fire fighting and some times non-catastrophic spills. For areas with high hazard potential, specific drills for dealing with potential catastrophic incidents are important.

  - -- Evaluation of operator awareness: by questioning them about what incidents they consider to be the greatest hazards in their areas and how they might respond to such incidents.

- Emergency Communications Systems

  - -- Communications systems available for dealing with emergencies: may include telephones, radios, signals, and alarms.

- Evaluation of the effectiveness and reliability of the communications system. Because telephone lines may be out of service in an emergency, radio communication is an important backup.

- Definition of communications responsibilities and plans for relaying information in times of emergency.

- Consideration of alternatives to telephone and radio communications, such as area wide alarm signals.

- Emergency Response Equipment

  - Emergency response equipment availability: may include air packs, chemical suits, medical packs, and mobile tool kits.

  - Evaluation of the effectiveness and reliability of the equipment. The total available supply of emergency breathing air is critical.

- Coordination with Outside Agencies and the Community

  - Evaluation of the availability of support facilities, equipment, and personnel. Support facilities include hospitals, emergency aid stations, and fire stations. Equipment includes fire vehicles, ambulances, and specialized tools. Numbers and skills of support personnel are noted. Because chemical plant operations can sometimes be esoteric to the outside community, the hazard potential of a facility may be reduced if outside authorities and emergency services are properly informed and are familiar with the plant and its operations.

Local fire departments should be aware of the methods and equipment necessary, to fight a chemical fire for each chemical in use. The plant's program in this regard is evaluated.

-- Consideration of plant participation in joint training activities with the community.

-- Consideration of the proximity of support facilities and response times. Response times longer than 15-20 minutes are reaching the extreme of utility for an emergency response.

-- Consideration of accessibility to the plant and various areas within the plant, especially to how emergency access and egress may differ from normal entrance and exit patterns.

-- Review of plans for emergency notification of the community and for community evacuation. While a community evacuation plan is beyond the control of the plant, recognition of the need for such a plan and steps the plant may have taken to have the community develop such a plan are noted.

-- Mutual aid from neighboring industry: is it available?

-- Evaluation of general community relations and of historical relations by discussions with plant personnel. This may be important in engaging community support in emergencies, as well as in securing the plant against possible sabotage.

APPENDIX C
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Alkane: A chemical compound consisting only of carbon and hydrogen in which the carbon atoms are joined to each other by single bonds.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Autocatalytic: A chemical reaction which is catalyzed by one of the products of the reaction.

Carcinogen: A cancer causing substance.

Containment/Control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Contingency Plan: A plan which describes the actions that facility personnel will take to minimize the hazards to human health or the environment from fires, explosions or accidental releases of hazardous materials.

Control System: A system designed to automatically maintain all controlled process variables within a prescribed range.

Creative Checklist: A list of major hazards and nuisances designed so that when an individual item from the list is associated with a particular material or a significant part of a unit, an image of a specific hazard or nuisance is generated as a stimulus to the imagination of members of a multidisciplinary team.

Creative Checklist Hazard and Operability Study: A Hazard and Operability Study which uses a Creative Checklist to stimulate a systematic, yet creative search for hazards.

Emergency Response Plan: A plan of action to be followed by source operators after a toxic substance has been accidentally released to the atmosphere. The plan includes notification of authorities and impacted population zones, minimizing the quantity of the discharge, etc.

Event Tree: A logic diagram which depicts all pathways (success and failure) originating from an initiating event.

Exothermic: A term used to characterize the evolution of heat. Specifically refers to chemical reactions from which heat is evolved.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Fault Tree: A logic diagram which depicts the interrelationships of various primary events and subevents to an undesired top event.

Fire Monitor: A mechanical device holding a rotating nozzle, which emits a stream of water for use in firefighting. Fire monitors may be fixed in place or may be portable. A fire monitor allows one person to direct water on a fire whereas a hose of the same flowrate would require more than one person.

Guide Word Hazard and Operability Study: A Hazard and Operability Study which uses Guide Words to stimulate a systematic yet creative search for hazards.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hazard and Operability Study: The application of a formal systematic critical examination to the process and engineering intentions of the new facilities to assess the hazard potential of maloperation of individual items of equipment and the consequential effects on the facility as a whole.

Hygroscopic: Readily taking up and retaining moisutre (water).

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Lachrymator: A substance which increases the flow of tears.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Mutagen: An agent that causes biological mutation.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping and vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Pyrophoric: A substance that spontaneously ignites in air at or below room temperature without supply of heat, friction, or shock.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Teratogenic: Causing anomalies of formation or development.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX D

TABLE D-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	(psig)+14.696)x(6.895)
Temperature:	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value;	Btu/lb	kJ/kg	2.326
Enthalpy:	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	Pa-s (kg/m-s)	0.001

*Calculate as indicated

Source: Adapted from Reference 22.

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